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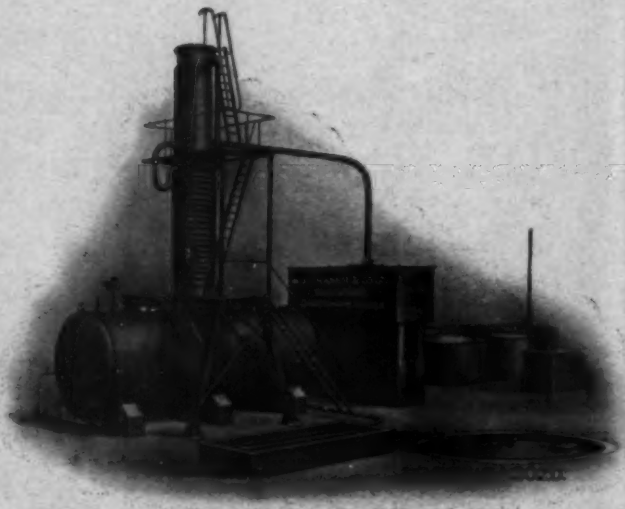

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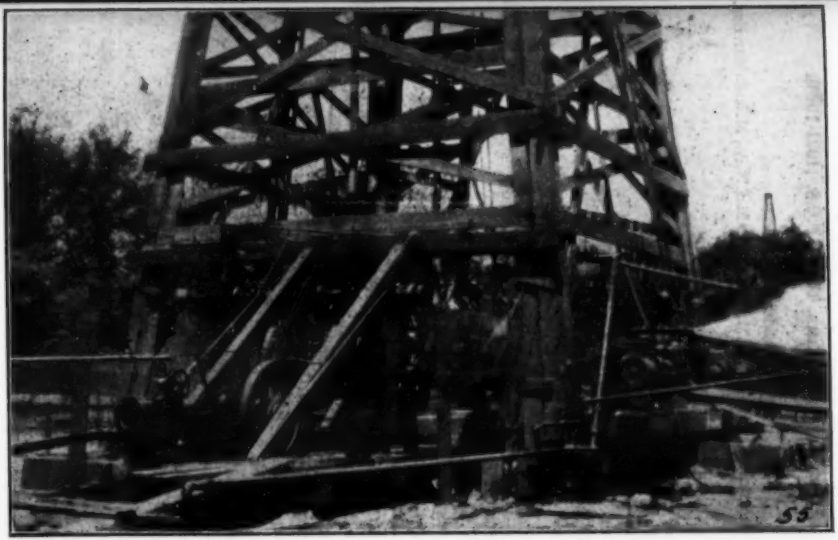

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CONTENTS.

	PAGE
Council and Officers	i–ii
Committees	ii–iii
General Notices :—	
Copyright	vi
Issue of Journal	vi
Changes of Address	vi
Papers and Articles	vi–vii
Binding of Journals	vii
Reprints of Papers	vii
Bibliography and Abstracts	vii
Medal for Student Members	vii
Advertisements	vii–viii
Appointments Register	viii
Library	viii–x
Personal Notes of Members and Special Notices	x
Conversazione at Aldine House	xi
The Sir John Cass Technical Institute	xii
Department of Scientific and Industrial Research ..	xii
Mellon Institute of Industrial Research	xiii
Petroleum Bibliography	xiii
Association of British Chemical Manufacturers	xiii
Current Petroleum Notes	xiv–xv
The Institution's New Offices	211
Heavy Grade Egyptian Crude Petroleum, by W. A. Guthrie, F.I.C., F.R.S.E., Etc.	212
Contribution *re* Prof. BRAME's paper on "Fire Hazards and Fire Extinction"	248
Aviation Spirit—Past, Present, and Future, by A. E. DUNSTAN, D.Sc., F.I.C., F.C.S., and F. B. THOLE, D.Sc., F.I.C., F.C.S.	249
The Nature of Lubrication in Engineering Practice, by T. E. STANTON, C.B.E., F.R.S., D.Sc., M.Inst.C.E., F.R.Ae.S.	260

PAGE

Oil Conference at Sixth International Mining Exhibition :

The Riddle of the Carpathians, by E. H. Cunningham Craig, B.A., F.R.S.E., F.G.S. 274

Oil Deposits and Tectonics of Vertical Pressure, by Dr. M. Kraus 276

Note on Genesis of Hydrocarbons and their Localization in certain zones of the Earth's Crust, by R. d'Andrimont 287

The Mode of Appearance of the Petroleum Deposits in the Carpathian Regions, with General Considerations on the Genesis of the Petroleum and the Salt of the Actual Deposits, by Dr. I. P. Voitesti 291

Oilfield Waste, by A. Beeby Thompson, O.B.E., M.I.Mech.E., M.Inst.M.M., F.G.S. 311

An Economic Study of Petroleum Mining by Underground Drainage, by J. A. Lautier .. 330

Current Bibliography, compiled by W. J. Wilson, F.I.C., A.C.G.I. 179A

Abstracts, compiled by S. Bowman, A.I.C., P. Dvorkowitz, Ph.D., H. Moore, A.I.C. F.C.S., F. G. P. Remfry, B.A., D.Sc., A.I.C., and T. A. Smith, B.Sc., F.I.C. 203A

PAGE

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

274

276

NOTICES.

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287

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291

311

Issue of Journal. The Journal is published in six bi-monthly parts per volume, viz., February, April, June, August, October and December. A brochure giving the History, Regulations and List of Members of the Institution was published in January, 1923, and the revised List of Members will be published periodically.

330

179A

All members receive these publications free of cost. Additional copies of the Journal are charged at the rate of 7s. 6d. per part, and of any other publication at the price stated on the wrapper.

203A

Changes of Address. Members are requested to notify any change of address to the Secretary, and also to advise the Parcel Post Department and the Letter Office in order that correspondence may be re-addressed.

Papers and Articles. Papers and articles should be written in the third person, and drawings, diagrams, etc., illustrating a subject should be suitable for direct photographic reproduction.

English equivalents of foreign weights and measures should be given, and it is suggested that a bibliography of the subject dealt with be appended.

All papers and articles submitted are assumed to be original communications unless otherwise stated, in which case reference to the previous publication should be given.

Members are invited to submit papers to be read at the General Meetings of the Institution, and are specially asked to forward articles for publication in the Journal.

* * *

Members desiring to receive advance galley proofs of papers to be read before the Institution should apply to the Secretary, informing him of the address to which the proof is to be sent.

Binding of Journals. Cases for binding the Journal can be obtained from Messrs. W. Speaight and Sons, Limited, 98, Fetter Lane, London, E.C. 4, at a cost of 1s. 6d. post free, remittance to accompany order.

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Orders for extra reprints should be sent to the printers when the manuscript is forwarded to the editor.

Bibliography and Abstracts. A bibliography of current literature is published with each issue of the Journal, together with abstracts of the more important articles and patent specifications, this supplement being paged separately to the Transactions. In order to make this section of the maximum value, members are requested to send any matter which may have been inadvertently overlooked to the editor.

Medal for Student Members. A medal and a prize of five guineas will be awarded annually by the Council to that Student Member of the Institution who shall, in their opinion, have presented a paper of outstanding merit during the year.

Advertisements. A number of Advertisements are inserted in the Journal, and information as to terms, etc., can be obtained from Mr. R. Donald Elcox, Advertisement Manager, Journal of the Institution of Petroleum Technologists, Aldine House, Bedford Street, Strand, London, W.C. 2.

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Appointments Register. A register of members requiring appointments is kept at the office of the Institution for the convenience of firms requiring the services of petroleum technologists, etc., it being understood that the Institution accepts no responsibility and gives no guarantee.

Library. The Institution's Library may be consulted between the hours of 11 a.m. and 4 p.m. daily. The additions made to the current and standard literature on petroleum and allied substances, since the publication of the last Journal, are :—

Interim Report of the Dominion Fuel Board, Ottawa, Canada. May 21st, 1923.

L'Industrie Des Schistes Bitumieux et des Torbanites. By Rear-Admiral P. Dumas.

Oil Flow Viscosity and Heat Transfer. By R. S. Danforth. (For Review.)

Report of the Fuel Technology Institute of the Czech Polytechnic High School in Prague for 1921. By Prof. Dr. Ferdinand Schulz.

From the American Petroleum Institute ;—

Estimates of Daily Average Crude Oil Production. June 6th, 1923.

Reports.—Imports of Petroleum at Principal United States Ports. June 6th, 1923.

Reports.—Receipts of California Oil at Atlantic and Gulf Coast Ports. June 6th, 1923.

* * * *

From the Institution of Automobile Engineers ;—

Proceedings of the Institution of Automobile Engineers. Part I.—1922–23.

From the British Engineering Standards Association ;—

Complete set of Specifications to date.

From the Imperial Mineral Resources Bureau ;—

The Mineral Industry of the British Empire and Foreign Countries. (War Period.) Graphite. 1913–1919.

From the International Institute Branch, Dept. of Agriculture, West Block, Ottawa, Canada;—

Descriptive List of Publications recently added to the Library.

From the Mellon Institute, U.S.A. ;—

Tenth Annual Report, 1923.

From the Ministry of Finance, Egypt ;—

Bulletin No. 12. Preliminary Geological Report on Wadi Gharandel Area. By F. W. Moon and H. Sadek.

From the U.S. Bureau of Mines Department of the Interior ;—

Bulletin 216. Bibliography of Petroleum and Allied Substances in 1919 and 1920. By E. W. Burroughs.

Serial No. 2482. Survey of Pacific Coast Petroleum Products. Part II.—Lubricating Oils. By E. C. Lane and N. F. de Jeanne. May, 1923.

Plan for Conducting Work under operating Regulations to Govern the Production of Oil and Gas. Under the Act of February 25, 1920. Public 146.

Technical Paper 328. The Motor Gasoline Surveys of 1920 and 1921.

From the U.S. Geological Survey, Department of the Interior ;—

Bulletin No. 686. Structure and Oil and Gas Resources of the Osage Reservation, Oklahoma. By David White and others. Together with Structure Maps.

Bulletin No. 729. Oil Shale of the Rocky Mountain Region. By Dean E. Winchester.

Bulletin No. 732. Geology and Ore Deposits of Shoshone County, Idaho. By J. B. Umpleby and E. L. Jones, Jr.

Bulletin No. 734. Deposits of Manganese Ore in the Bartlesville District, Arkansas. By Hugh D. Miser. (With a chapter on the Mining and Preparation of the Ores. By W. R. Crane.)

Bulletin No. 735I. Diamond-Bearing Peridotite in Pike County, Arkansas. By Hugh D. Miser and Clarence S. Ross.

Bulletin No. 735J. The Los Burros District, Monterey County, Arkansas. By James M. Hill.

Bulletin No. 736H. Stratigraphy of the El Dorado Oil Field, Arkansas, as determined by Drill Cuttings. By J. Gilluly and K. C. Heald.

Bulletin No. 740. Mica Deposits of the United States. By D. B. Sterrett.

Bulletin No. 741. The Jarbridge Mining District, Nevada. By F. C. Schrader.

Bulletin No. 743. Geology of the Oatman Gold District, Arizona. By C. E. Ellsworth and F. L. Ransome.

Bulletin No. 751A. Continuity of Some Oil-bearing Sands of Colorado and Wyoming. By Willis T. Lee.

Professional Revision of the Flora of the Green River Formation. Paper 131F. By F. H. Knowlton.

Water-Supply Paper No. 480. Surface Water Supply of the United States, 1918. Part X.

Water-Supply Paper No. 483. Surface Water Supply of the United States, 1918. Part XII.

Water-Supply Paper No. 493. Hydroelectric Power Systems of California and their Extensions into Oregon and Nevada. By F. H. Fowler.

Water-Supply Paper No. 504. Surface Water Supply of the United States, 1919–1920. Part IV.

Water-Supply Paper No. 508. Surface Water Supply of the United States, 1919–1920. Part VIII.

The Council would be grateful to members, who are authors of books on petroleum or allied substances, if they would kindly present a copy of their works to the Library of the Institution, and for review in the Journal.

PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.

Dr. J. A. L. Henderson left on the 27th of July for Canada and the United States, and expects to be absent from England for about six months.

Mr. H. R. Berry has proceeded to Thayetmyo, Upper Burma.

Mr. Harold Dabell has returned from Egypt.

Mr. H. S. Denny, who is now in New York, will be returning to England at the end of August.

Mr. T. R. H. Garrett has left for Roumania.

Mr. W. A. Guthrie is on his way back to Egypt.

Mr. H. Mejor is now in Roumania.

Mr. John Towers is now in Ecuador.

MR. W. G. HERLIHY has returned from Persia.

MR. G. E. OWLES is back home from Peru.

MR. W. CROMPTON has proceeded to Rangoon, Burma.

MR. G. S. FFOULKES-JONES has proceeded to Trinidad.

MR. A. S. MATHESON has proceeded to Buenos Aires.

MR. E. F. WHITTINGDALE has proceeded to Roumania.

PROF. R. R. THOMPSON has been appointed by the Colonial Office as Adviser on Petroleum and Mining to the Government of Trinidad, and leaves for a short visit to the island in August.

We much regret to announce the death of Captain WILLIAM LEOPOLD SAMSON, D.F.C., Associate Member, who passed away in June.

It is with great pleasure that we have to announce that, on the occasion of His Majesty's Birthday, the honour of a Baronetcy was conferred upon our Honorary Treasurer, Sir WILLIAM PLENDER, G.B.E., to whom we tender our heartiest congratulations.

We are indebted to the International Air Congress, London, 1923, for permission to reproduce in this Journal two papers which were read before the Congress, namely :—"Aviation Spirit—Past, Present, and Future," by A. E. Dunstan, D.Sc., F.I.C., F.C.S., and F. B. Thole, D.Sc., F.I.C., F.C.S., and "The Nature of Lubrication in Engineering Practice," by T. E. Stanton, C.B.E., F.R.S., D.Sc., M.Inst.C.E., F.R.A.S.

We have received from the publishers, Messrs. Charles Griffin & Co., a copy of the second edition of "Redwood and Eastlake's Petroleum Technologist's Pocket Book," for review.

The "At Home" at the 6th International Mining Exhibition, Royal Agricultural Hall, on June 9th, was attended by some 200 members and friends was a great success, the guests being received by the President, Mr. H. Barringer, and his wife. A brief and felicitous speech was made by the President, welcoming the members and their friends and thanking Mr. H. Greville Montgomery, the organiser of the Exhibition, for the courtesy which he had extended to the Institution.

CONVERSAZIONE AT ALDINE HOUSE.

At a house-warming of the Institution's new offices at Aldine House, Bedford Street, Strand, London, W.C. 2, a detailed description and photographs of which will be found elsewhere in this

Journal, the President and Council will be At Home to members and their friends (ladies included) on Wednesday evening, October 3rd, from 8 to 10 p.m. During the evening scientific apparatus will be exhibited and demonstrated, and light refreshments will be served. Invitations will be sent out in due course.

THE SIR JOHN CASS TECHNICAL INSTITUTE.

Extract from the Report on the Work of the Department of Petroleum Technology for the Session 1922–1923.

The experience gained during the first year's work in the department of Petroleum Technology proved of much value in arranging the courses of instruction for the second session, and it is very satisfactory to be able to report that, whilst the element of novelty associated with the beginning of a new branch of study has necessarily abated, the demand for instruction specifically adapted to the requirements of those engaged in the petroleum industry has been well maintained.

The courses were inaugurated by an introductory lecture, by Mr. T. Dewhurst, on the "Origin of Petroleum," which was followed by special lectures given by Mr. E. M. Bailey, Sir Frederick W. Black, K.C.B., Prof. J. S. S. Brame, Sir John Cadman, K.C.M.G., Mr. A. Frank Dabell, Dr. A. E. Dunstan, Mr. J. L. Jeffery, Mr. P. Kerr, Mr. James Kewley, Prof. R. R. Thompson, Mr. J. McConnell Sanders, and Mr. W. R. A. Weatherhead. Instruction by experts of the high standing of these lectures is of the greatest value as a means of imparting first-hand knowledge to the students, and the Governors of the Institute very much appreciate the services that have been rendered in this connection.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.

The Lord President of the Council has accepted with much regret the resignation of Sir George Beilby, LL.D., F.R.S., as Director of Fuel Research and Chairman of the Fuel Research Board, and has appointed Mr. C. H. Lander, D.Sc., M.I.Mech.E., A.M.Inst.C.E., to be Director of Fuel Research, and Sir Richard Threlfall, K.B.E., F.R.S., to be Chairman of the Board. Sir George Beilby retains his membership of the Advisory Council of the Department, and has consented to act as Honorary Advisor to the Board. The Hon. Sir Charles Parsons, K.C.B., F.R.S., continues his membership of the Board for a further period, and the following gentlemen have

accepted appointment as additional members :—Mr. R. A. Burrows, Sir John Cadman, K.C.M.G., D.Sc., Dr. Charles Carpenter, C.B.E., D.Sc., Mr. Samuel Tagg, Prof. Sir James Walker, D.Sc., LL.D., F.R.S., and Prof. R. V. Wheeler, D.Sc.

MELLON INSTITUTE OF INDUSTRIAL RESEARCH.

We have received the Tenth Annual Report of the Mellon Institute of Industrial Research of the University of Pittsburg, dealing with the Industrial Fellowship System which was inaugurated at that University on March 1st, 1911. The Mellon Institute was established on a permanent basis in March, 1913, as a memorial to Judge Thomas Mellon and to Dr. Duncan, and the following paragraph extracted from the report presents briefly the working plan of the Institute :—

"In accordance with the System of research, an individual industrialist, a company, or an association of manufacturers, having a suitable problem or group of problems requiring investigation, may become the donor of an Industrial Fellowship, provided the problems are of sufficient scope to warrant the services of at least one man for a period of at least one year, and, also, provided there is no other investigation in progress in the Institute on the research topic which is of interest to the prospective donor."

PETROLEUM BIBLIOGRAPHY.

The United States Department of the Interior has resumed publication of the monthly bibliography on petroleum and allied substances, which was discontinued several months ago. A limited number of the bibliographies are available for distribution, and individuals or libraries desiring to be placed on the mailing list should address their applications to the Department of the Interior, Bureau of Mines, Customhouse, San Francisco, California.

ASSOCIATION OF BRITISH CHEMICAL MANUFACTURERS.

The Annual Dinner of the Association of British Chemical Manufacturers, at which the Secretary of this Institution had the honour of being present, was held at the Holborn Restaurant on July 12th last, Sir Max Muspratt, Bart., Chairman of the Association, occupying the chair.

CURRENT PETROLEUM NOTES.

The receipt of notes of interest for insertion under this heading will be welcomed by the Editor.

POLAND.—According to the *Polish Economic Bulletin*, the production of crude petroleum in the Boryslaw Basin in March, 1923, amounted to 43,000 metric tons, an increase of 6900 metric tons over the preceding month, and of 1130 metric tons over March, 1922. In the Boryslaw-Tustanowice-Mraznica field, of a total of 639 wells, 333 were producing oil and gas, 30 were producing gas only, 171 were drilling, 136 were in course of erection or reconstruction, and 140 were temporarily shut down.

Of the total production of petroleum products in Poland in 1922, some 60 per cent., amounting to 36,130 wagons of 10,000 kilos. each, was exported, an increase of 2765 wagons over 1921. Of the total exports, 12,928 wagons, or 36 per cent., went to Germany; 19 per cent., or 6805 wagons, to Austria; 17 per cent., or 6244 wagons, to Czecho-Slovakia; the remaining 28 per cent. being distributed to various countries.

UNITED KINGDOM.—The imports of petroleum and its products into the United Kingdom for the first six months of 1923, are given in the table below, as compared with the corresponding period of 1922:—

	1923.		1922.	
	Quantity. Imperial gallons.	Value. £	Quantity. Imperial gallons.	Value. £
Crude petroleum ..	146,495,842	2,282,816	94,407,119	1,350,625
Lamp oil	70,390,202	1,594,066	80,503,140	2,167,243
Motor spirit	157,832,579	8,315,180	172,966,645	11,605,514
Other spirit	1,001,410	37,821	2,200	266
Lubricating oil ..	51,764,900	2,872,634	34,155,420	2,329,397
Gas oil	35,599,234	532,552	41,982,352	708,326
Fuel oil	165,675,377	2,158,609	203,286,042	3,203,770
Other sorts	28,306	3,568	22,714	2,586
Total	628,787,850	£17,797,246	627,325,632	£21,367,727
Paraffin wax (cwts.)	710,292	£578,054	431,462	£422,199

The total amount of oil imported during the period January to June, 1923, shows an increase of 1,462,218 imperial gallons over 1922, while the value shows a decrease of £3,570,481. The imports of paraffin wax show an increase in quantity of 278,830 cwts., and in value of £155,855.

The exports of petroleum and its products for the first six months of this year, as shown in the following table, increased over the first six months of 1922 by 33,321,108 imperial gallons in quantity, and by £764,004 in value, while the exports of paraffin wax for the

same period decreased in value to the extent of £56,593, and in quantity by 35,990 cwts.

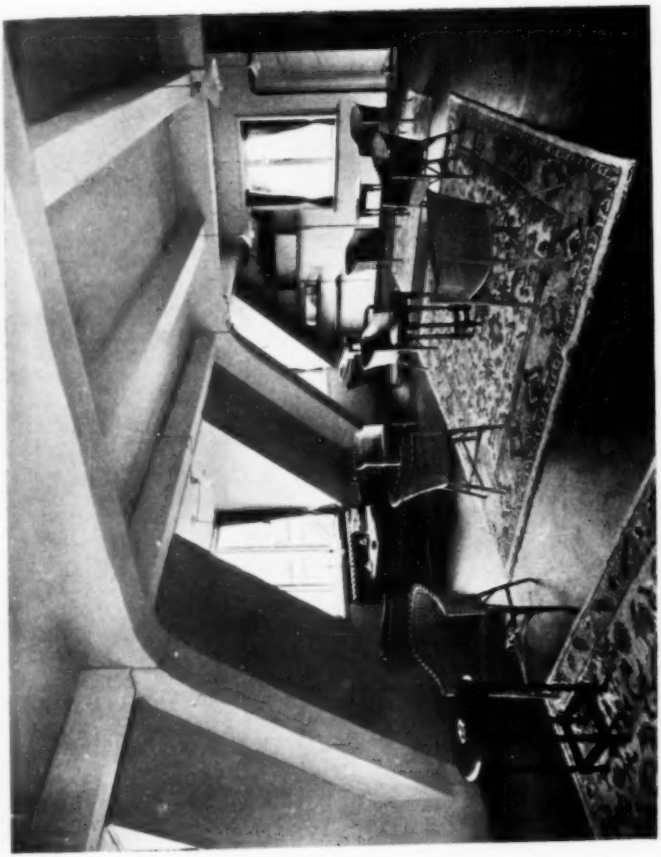
	1923.		1922.	
	Quantity.	Value.	Quantity.	Value.
Petroleum and its products:	Imperial gallons.	£	Imperial gallons.	£
British manufacture and produce ..	37,435,831	1,192,064 ..	9,261,180	605,707
Re-exports of foreign and colonial produce	25,378,716	1,378,344 ..	20,232,259	1,200,697
Total	62,814,547	£2,570,408 ..	29,493,439	£1,806,404
Paraffin wax:	Cwts.		Cwts.	
British manufacture and produce ..	67,060	69,678 ..	75,564	96,683
Re-exports of foreign and colonial produce	23,255	50,037 ..	50,741	79,625
Total	90,315	£119,715 ..	126,305	£176,308

ITALY.—The United States Commercial Attaché reports that the Italian Ministry of Industry and Commerce has, on the recommendation of the Royal Experimental Station for Oil and Greases of Milan, appointed a technical commission to study the necessity for establishing standard specifications covering petroleum products, it being desirable to determine specifications for the various oils, both as a guide to the producer and to enable the consumer to choose a product suitable to his needs.

GERMANY.—It is reported that the extraction of oil by means of pits or shafts sunk into an oil-sand, is now being carried out at Wietze, near Hanover, the oil being obtained by a washing system after the sand has been brought to the surface.

HELIUM GAS.—According to Prof. J. C. McLennan, in a pamphlet issued by the British Science Guild, the production of helium from natural gas in the United States amounts to 30,000 to 40,000 cubic feet daily. Helium, which was first discovered in the sun 27 years before it was found on the earth, is the lightest gas next to hydrogen, and being non-inflammable and non-explosive, is particularly suited for the filling of airship envelopes. Its lifting power is only 8 per cent. lower than that of hydrogen, and it can be mixed with that gas to the extent of 15 per cent. without the mixture becoming inflammable or explosive in air. Of the natural gases within the British Empire, those from Ontario and Alberta, Canada, are richest in helium, with about one-third per cent., while the helium content of the gas from Heathfield, Sussex, is one-fifth per cent., and from King Spring, Bath, one-sixth per cent. In Texas natural gases are known to exist containing one to two per cent. of helium.

COUNCIL ROOM. [*Photo by The Telle Co.*



MEMBERS' ROOM. [*Photo by The Telia Co.*

THE INSTITUTION'S NEW OFFICES.

THE LIBRARY. [Photo by The Folio Co.

THE INSTITUTION'S NEW OFFICES.

Aldine House, Bedford Street, Strand, London, W.C. 2.

The moving into, furnishing of, and settling down at the new offices, of which a brief description was given in Journal No. 37, has now been completed.

These offices, which are on the fourth (the top) floor of the building, have been entirely re-decorated and re-fitted. The very considerable increase in floor space (about 2400 sq. ft. as against about 600 sq. ft.) has necessitated the purchase of a large amount of new furniture and carpets. The rooms are airy and well-lighted, and heating is provided by means of hot-water radiators.

The Members' Room, of which two photographs are reproduced, has been furnished with two writing tables, six occasional tables, and eighteen wicker chairs. This room is equipped as a writing and smoking room, where members may meet their friends without disturbing those using the Library. The size of the room and the portability of its furniture, will admit of its being used for meetings at which only small attendances are anticipated.

The Library, as will be seen from the photograph, is a large, well lighted room, and has plenty of space available for additional books. Being fitted with a skylight the maximum amount of light is obtained without resort to artificial means. As before, the Library is open to members from 11 a.m. to 4 p.m. daily (Saturdays to 1 p.m.).

The Council Room, being entirely separate from the Library and the Members' Room, ensures that Council and Committee Meetings will in no way interfere with members who are desirous of using either of those rooms. This room also serves as the Secretary's office.

The General Office accommodation is commodious, and consequently the staff are working under very much more comfortable conditions than was previously the case.

Generally speaking the offices are, in every way, a very great improvement on those at John Street, and it is hoped that members will take an early opportunity of visiting them and making use of the advantages offered.

As mentioned in the Preliminary to this Journal, a formal opening, in the nature of a Conversazione and Exhibition, will take place on Wednesday evening, October 3rd, from 8 to 10 p.m., for which members and their friends will receive an invitation in due course.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE Seventy-first General Meeting of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street. Adelphi, London, W.C. 2, on Tuesday evening, May 8th, 1923, the President, Mr. H. Barringer, M.Inst.C.E., M.I.Mech.E., M.I.N.A., occupying the Chair.

In opening the meeting, the **President** said that he would like to again remind Students that the Institution was granting a Medal and a Prize of £5 for the best paper of merit which was sent in before December 31st, and he hoped there would be a good response. It was hoped to give the Students further encouragement, and a scheme was being considered by the Council, particulars of which would be published later.

In the absence of Mr. Guthrie, who was in Egypt, the following paper was read by Prof. J. S. S. Brame :—

Heavy Grade Egyptian Crude Petroleum.

By W. A. GUTHRIE, F.I.C., F.R.S.E., ETC. (Member.)

THE VALUE OF CHEMICAL STUDY.

IT was intended to have discussed fully in this paper the exhaustive chemical examination of the heavy grade Egyptian crude petroleum as a contribution to the general study of its origin and occurrence, but pressure of other duties has prevented its development and completion, and the paper will be devoted therefore to a more general *résumé* of the nature of the oil, and to a discussion of two alternative methods of refining in order to get the best out of it. It is hoped at a later date, however, to put before the members the results of the complete chemical examination, for although some workers believe that the results obtained do not compensate for the enormous amount of time and study necessary, a different opinion is held by the writer and his colleagues. In their view the relation between the chemical composition of various oils (for instance, the two distinct types of Egyptian crude oil—one light paraffin base, and the other heavy mixed base) and their mode of occurrence must some day throw light on their origin. The writer is indeed convinced that if more detailed chemical work had been done in

the early days of the industry there would not be so much doubt to-day on the question of origin.

Geology.

Before entering into the subject matter proper, and as an introduction to the study of this oil, it will be useful to recall something of the "Geology of the Egyptian Oilfield."* According to Hume, seepages of oil at Zeitia, Jemsa and Gebel Tanka, the latter on the coast of West Sinai, led to the first borings for oil. Important supplies were first obtained at Jemsa in 1908, where the petroleum was present in porous dolomitic limestone associated with gypsum, which has been proved to be of Miocene age. Subsequently in 1913 borings were commenced at Hurghada. These traversed the typical Miocene succession as developed on the surface in the Zeit Hills—*viz.*, below a thick series of gypsum followed dolomitic limestone or the characteristic Globigerina Marl, the base of the Miocene formation, of which the above strata form part, being constituted of a flint conglomerate. Below this stratum is a series of sands and shales (including carbonaceous varieties), in which the main oil is present. These beds are regarded as of Upper Cretaceous age overlying the typical Nubian Sandstone. A third oilfield of small extent is that of Abu Durba, on the west coast of Sinai, twenty-five miles northward of Tor, where there were indications of the former presence of oil in the Nubian Sandstone. Borings have shown that petroleum is present in a series of gravels of igneous rocks occurring between the outcrop of the Nubian sandstone and the shore. Whether the oil is present in deeper seated strata at this locality has still to be proved.

The heavy grade crude petroleum which will be discussed in this paper is found at Hurghada (Rargada), situated some 200 miles south-east of Suez, on the western shore of the Gulf of Suez. The oil is found at a depth of from 1600 to 2000 feet. From the striking of oil in the first well in October, 1914, until the beginning of the present year, 1,201,868 metric tons have been won from the field, and the present net production averages 3500 tons per week. A proportion of the production of the field is "wet"—*i.e.*, contains approximately 30 per cent. of salt water in the form of a very refractory brine emulsion, which is very difficult to de-emulsify, and which has caused a great deal of trouble and difficulty.

In the latter part of 1918, when the trouble looked like becoming acute, the writer carried out certain experiments, which seemed to him to confirm the view that these emulsions were amenable to the electrical dehydrating treatment. The installation at a later date of a number of these electrical dehydrating units on the field may

* W. F. Hume, Journ. Inst. Petr. Techn., vii, 394-411, Dec. 1921.

perhaps be cited as sufficiently demonstrating that the application of this treatment on a large scale is considered to be a commercial proposition.

The Characteristics of the Dry Oil are as follows :—

Sp. gr. at 15·5° C.	0·907/0·925
Flash point (close test)	Below 45° F.
Viscosity (Redwood No. 1) at 60° F.	3844 secs.
Viscosity (Redwood No. 1) at 100° F.	396 secs.
Viscosity (Redwood No. 2) at 60° F.	418 secs.
Viscosity (Redwood No. 2) at 70° F.	105 secs.
Sulphur	2·22/·5%
Asphalt (insoluble in pentane)	10/11%
Paraffin wax (M.P. 117·5° F.)	7/8%

The oil is therefore a mixture of paraffin base and asphaltic base petroleum ; it has quite a pleasant smell, despite its sulphur content, and when seen in a thin film is brownish-black in colour, while the calorific value is just under 19,000 B.Th.U.'s per pound. The oil contains traces of Vanadium and Nickel. The ultimate analysis is : carbon, 85·15 per cent. ; hydrogen, 11·71 per cent. ; sulphur, 2·25 per cent. ; oxygen and nitrogen (by difference), 0·89 per cent.

Although a good deal of time and study has been expended on the chemical examination of the oil, this part of the work is still very far from being complete, for, as all workers in this field know, the problem is an extremely difficult and complex one. It is further complicated by the fact that the only practical known method of separating the constituents of a crude oil is fractional distillation, which, at any rate when conducted at atmospheric pressure, alters the composition of the fractions to an extent not fully realised by many investigators. In order to obtain fractions which will have a closer relationship in chemical composition to the state in which they exist in the original crude oil, distillations have been conducted by the writer right down to coke, under a vacuum of 28 inches, and using liberal supplies of steam. It is interesting to note that by this means the final temperature of the vapour has been reduced from 371° C. to 223° C. Not only so, but whereas in the earlier fractions from these vacuum distillations, very little, if any, bromine is absorbed at all ; in the earlier fractions from an atmospheric distillation unsaturated hydrocarbons exist to the extent of from 3 to 10 per cent., as determined by the amount of bromine absorbed in 15 minutes in the dark. Moreover, in the later fractions from an atmospheric distillation as much as 40 per cent. of unsaturates have been found, while in the same fractions, from a vacuum distillation these have been reduced to from 10 to 20 per cent. It is extremely difficult to say with any degree of certainty what these compounds are which absorb bromine in the dark in 15 minutes, but the absorption cannot be unconnected with the presence of olefines and di-olefines. In this respect, it is also interesting to

observe that whereas the unsaturates present in the fractions from the atmospheric distillation are almost entirely removed by 80 per cent. sulphuric acid (pointing to di-olefines) the unsaturates in the fractions from the vacuum distillation are only partially removed by the same reagent. It must also be admitted that it is difficult at this stage to say with certainty what these bodies are. All this, however, emphasises the importance that when investigating the chemical composition of a crude oil the fractional distillation should be conducted at as low a temperature as possible with a view to reducing to a minimum the decomposition and consequent change in chemical character. In the estimation of unsaturated hydrocarbons bromine was used instead of iodine, after a long series of tests had shown that the iodine and bromine values were comparable. It was found in the summertime in Egypt that whereas the bromine absorptions remained concordant, the iodine values became variable, owing to the impossibility of keeping the iodine chloride at the high temperatures.

Although, as stated above, the chemical examination of the oil is far from being complete, it has been ascertained that in the first six fractions from a vacuum distillation, amounting to 30 per cent. in the original crude oil, there is an average of 16 per cent. of aromatic hydrocarbons. The final boiling point in vacuo was 153° C. The aromatics were determined by the Tizard-Marshall aniline point method and checked by the change in specific gravity, after sulphonation with 98 per cent. sulphuric acid. In the remainder of this 30 per cent. of the original crude, paraffin hydrocarbons predominate, naphthenes being present only in very small amount. Of the intermediate and higher boiling fractions, nothing very definite is yet known, excepting that both contain considerable quantities of unsaturated olephenic hydrocarbons and the latter much solid paraffin wax.

Commercial Products.

The oil, when distilled in the ordinary way for commercial products, yields 6 to 8 per cent. benzine boiling below 150° C., and 14 to 15 per cent. kerosene, boiling between 150 and 290° C.

The following may be given as a typical laboratory analysis :—

	%	Sp. gr. at 15·5° C.	Flash point, Abel close test. ° F.	Viscosity at 100° F. Redwood No. 1. secs.
Benzine (below 150° C.)	8·0	0·731		
Kerosene (150°C./290° C.)	15·0	0·822	108	
Residue (above 290° C.)	76·0	0·968	302	5707
Loss	1·0			
	100·0			

Benzine and Kerosene.

The benzine and kerosene fractions can be refined to first-class finished products. The benzine is not entirely free from sulphur compounds (0·015 per cent. sulphur, determined by the lamp method), but these are not present in an objectionable form. The "doctor" test is negative, and when a piece of copper foil, cleaned by boiling with a 10 per cent. potassium cyanide solution, is placed in the Engler distillation flask, only a very faint tarnishing of the copper foil takes place when 94–95 per cent. of the benzine has distilled over. A part only of the sulphur in this benzine is removed by treating with concentrated sulphuric acid. Samples of the benzine having a specific gravity, 0·730–735 at 15·5° C., show the following results when distilled in a standard Engler flask, the rate of distillation being two drops per second :—

	°C.
Initial boiling point	50
40/45%	100
94/95%	150
Flask dry	165

The kerosene (specific gravity, 0·820 at 15·5° C.) can be refined to a water white kerosene of high illuminating value, by treatment with 2 per cent. of sulphuric acid (1·84 specific gravity), finishing with a fuller's earth or florida clay treatment.

Residue.

The residue is very thick and viscous, becoming semi-solid at temperature slightly below 15·5° C., and having a viscosity at 100° F. in Redwood's No. 1 Viscometer of anything from 5000 to 7500 secs. The viscosity cannot be determined at all in the No. 2 Viscometer at 32° F., or even at 60° F. The high viscosity is, of course, due to the asphalt and paraffin wax content, which amounts to 15·25 per cent. of the former, and 10·35 per cent. of the latter. The calorific value of the residue is 18,370 B.Th.U.'s.

At this point it will be useful to digress into generalities for a moment. The remark is often heard that the crude oil from this or that country is of very low grade, and can only be usefully treated by "topping"; *i.e.*, removing the small benzine fraction, and perhaps a portion of the kerosene fraction, and using the residue as fuel oil for burning under steam boilers. This view has been expressed, with some apparent justification, in respect of the heavy grade crude oil from the Hurghada field. But the use of "topped" oil in this manner must be generally regarded as wasteful if it can be proved that valuable products might be obtained from

oil so treated, and there are, in fact, few, if any, crude oils which will not yield under proper treatment more valuable products than fuel for steam boilers. The obtaining of products referred to in this instance does not necessarily mean an increase in the benzine and kerosene yield, although this is always possible by "cracking," but merely the extraction of the full normal content of these two products, with the production as well of varying quantities of solar oil, Diesel oil, lubricating oils, paraffin wax, and pitch for road-making and other purposes, according to the needs of the country in which the oil is found.

It seemed to the writer to become the more essential that research work should be carried out on the "topped" oil or residue from Hurghada crude, owing to its unsatisfactory nature and its unsuitability, for instance, for use in Diesel or semi-Diesel engines. Not only so, but owing to its viscous character it is most inconvenient to transport and handle in the winter time in Egypt, when in actual fact it becomes semi-solid, causing loss of time, and sometimes even of oil, to the consumer, owing to the difficulty of expeditiously and completely removing it from barrels and tank waggons. This difficulty has been dealt with in practice, in one or either, or both, of two ways; firstly, by leaving some of the kerosene in the residue, when, however, the latter still remains unsatisfactory, for even if the last 7 per cent. of the kerosene fraction is left in, the viscosity in Redwood's No. 1 instrument at 100° F. is still 3500 secs.; secondly, by mixing the residue with thin foreign fuel oil in order to reduce the viscosity. The former procedure is neither satisfactory nor economical, while the latter would not be possible for any company operating in Egypt which could not rely upon a constant supply of imported oil of suitable quality. Methods will, therefore, now be discussed in which an endeavour has been made to make the refining of this heavy grade oil into first-class products a self-contained operation. It may be mentioned here that these methods are now being tried out—with a large measure of success—on the manufacturing scale in the Egyptian Government Petroleum Refinery at Suez. If and when they have been proved successful and economical on this scale, the result might well be to encourage the treatment of Egyptian crude on its own merits, and thereby at one and the same time to enhance the value of Egyptian oil, and remove a possible deterrent to oil companies contemplating operations in Egypt.

In order to attain the object in view two courses appeared to be open from the nature of the crude oil—namely, either to extract the paraffin wax and manufacture lubricating oils, or to break down the paraffin wax and extract the hard asphalt as pitch.

In pursuance of the line that it would be of no benefit to Egypt to extract and refine paraffin wax, since it is not required in any

industry in the country, although, as will be briefly shown later, its successful extraction is quite practicable, experimental work was directed to breaking down the paraffin wax in the "topped" oil into thin oil suitable for Diesel engines, which would not solidify in the winter time, and to leaving the asphalt behind as a pitch for road-making. The experimental work was carried out in five-gallon iron stills, made by Messrs. Fraser and Co., of Dagenham, Essex, one a horizontal still which can be used either for ordinary atmospheric distillation or for distillation *in vacuo*, and the other a vertical pressure still in which distillations can be conducted at 60 lbs. pressure and over.

It was early realised that the two objectives—namely, a thin Diesel oil and a good pitch for road-making—would not be attained in the one operation, since the moderate "cracking" distillation necessary for breaking down the paraffin wax compounds had a deleterious effect on the resulting pitch. The "cracking" distillation decomposed the asphalt to a certain extent with the production, in varying quantities, of free carbon, which is the worst defect a pitch can have, since it reduces its elasticity, and inclines it to crumble on the road surface. The production of good quality pitch became the first objective, and this was attained by distilling the residue (after all the benzine and kerosene had been extracted) down to pitch with the aid of liberal supplies of superheated steam. The properties of the pitch will be discussed later.

The distillate was collected in 5 per cent. fractions, and the first 23–24 per cent. (calculated in the residue) was thin enough for all purposes, but the next 37 per cent. contained the paraffin wax and was solid at laboratory temperatures in the winter. This portion was redistilled, either under slight pressure (4—5 lbs.), or in a slow "cracking" distillation using the minimum of steam, when the resulting distillate was again thin enough for all purposes. The following may be given as average details of many such distillations:—

Specific Gravity of the Residue used 0·975 at 15·5° C.

	%
Paraffin wax distillate	60·6
Hard pitch	39·0
Loss	0·4
	100·0

The first five fractions of the distillate, amounting to 23·5 per cent., were mixed together (distillate "A"), and had the following characteristics:—

Sp. gr. at 15·5° C.	0·890
Flash point (close test)	161° F.
Flowing point	6·5° C. (43° F.)
Viscosity at 100° F. (Redwood No. 1)	51 secs.

Fractions 6 to 13, amounting to 37·1 per cent., were mixed together (distillate " B "). This was solid at 65° F., and contained 15 per cent. of paraffin wax, and had a specific gravity of 0·920 at 15·5° C. distillate " B " was then subjected to a mild " cracking " distillation. Whether this distillation was conducted under a slight pressure (4–5 lbs.) or merely slow atmospheric, using the minimum of steam, did not appear to make much difference to the results obtained, which were as follow :—

The final temperature of the Vapour was 320° C.

	%
Thin distillate (distillate " C ")	92·3
Residue (inferior fuel oil)	6·7
Loss	1·0
	100·0

Distillate " C " was thin and mobile, and had the following characteristics :—

Sp. gr. at 15·5° C.	0·881
Flash point (close test)	40° F.
Flowing point (tube method)	—4° C. (24·8° F.)
Viscosity (Redwood No. 2) at 32° F.	200 secs.
Viscosity (Redwood No. 1) at 60° F.	53 secs.

These figures show how susceptible the paraffin wax in this oil is to moderate " cracking," and that as a result of this distillation the high melting point wax has entirely disappeared. The flash point which is inclined to be too low is easily put right by steaming or air blowing with very little loss.

If these two results be combined the following percentages are obtained on the residue used :—

	%
Distillate " A "	23·5
Distillate " C "	34·2
Pitch	39·1
Inferior fuel oil	2·5
Loss	0·7
	100·0

The final results on the crude oil become :—

	%
Benzine (below 150° C.)	8·0
Kerosene (150° C. to 290° C.)	15·0
Solar or Diesel oil	43·2
Hard pitch	29·3
Inferior fuel oil	1·9
Loss	2·6
	100·0

The Solar or Diesel oil has the following characteristics :—

Sp. gr. at 15·5° C.	0·886
Viscosity at 32° F. (Redwood No. 2) ..	960 secs.
Calorific value	19,166 B.Th.U.'s per lb.

This Diesel distillate was obviously too good for practical use in the climatic conditions of Egypt as, apart from its thinness, it is, being a distillate, entirely free from asphaltum.

A thin fuel oil was therefore obtained from the viscous residue, and the next question was to find out how much of this residue could be mixed with it without detriment to the resulting fuel oil. Mixtures were consequently made in varying proportions using a very viscous semi-solid residue of 0·984 specific gravity. The properties of three such mixtures are as follows :—

No.	Nature of mixture.	Sp. gr. at 15·5° C.	Viscosity, Redwood No. 1 at 100° F. secs.	Flowing point (tube method). °C.	% Asphalt.
A	25% Residue 75% Diesel	0·910	73	4	3·7
B	50% Residue 50% Diesel	0·934	193	10	7·3
C	75% Residue 25% Diesel	0·959	962	15·5	11·0

The hard asphalt was determined by precipitation from petroleum ether, pentane being always used in this work for this purpose. It will be seen that certainly mixture A, and possibly mixture B, is good enough for internal-combustion engines of the Diesel and semi-Diesel type, while mixture C is a first-class Boiler Furnace Oil. It is noted in this connexion that the Standardization Committee of this Institution have deferred making any recommendation as to the percentage of hard asphalt permissible in a fuel oil for Diesel and semi-Diesel engines, although it is believed experience has shown that, in most types of engine, 5 to 7 per cent. does not cause any trouble over long periods of running, provided the body of the oil is thin enough to dissolve the asphalt and so make it easily combustible.

It will be observed from these figures that the new Boiler Furnace Fuel Oil will be composed principally of the original viscous residue, and that even the Diesel oil will contain 40 to 50 per cent. in its composition, the thin distillate being only used for thinning down. So that it would only be necessary to redistil about 40 per cent. of the heavy residue in order to manufacture first-class fuel oil products.

Properties of the Pitch or Bitumen.

The next points to be discussed are the properties and the suitability of the pitch, resulting from the distillation of Hurghada residue, for road-making and road-painting. It is realised that this is a contentious question, and will give rise to much difference of opinion, owing to the presence in the pitch of from 8 to 10 per cent. of paraffin wax. Speaking broadly, however, the writer was, and still is, of the opinion that a certain amount of paraffin wax cannot be deleterious, provided the physical properties laid down and found suitable for such a product, and, in particular, those generally grouped under the convenient term cementitiousness, are right. Instead of being objectionable the presence of paraffin wax should be an advantage, since it will make the pitch more chemically stable and less liable to disintegrate and crumble on the roads. In this connexion, it is understood that, although until recently many specifications stipulated the maximum percentage of paraffin wax which was permissible, this has now been discontinued as the result of experience. And as Abraham, in *Asphalt and Allied Substances*, remarks:

> "It is now generally conceded that there is no rational bearing between the solid paraffins in asphaltic products and their quality. The determination of paraffin wax is therefore of value only for purposes of identification."

The method of determining the amount of paraffin wax in a pitch or bitumen still appears to be a vexed question, some workers using one method and some another, so that the results are never comparable and the Standardisation Sub-Committee No. 6 does not appear, so far, to have made any definite recommendation on the matter. When it is stated that the pitch made from Hurghada residue contains 8 to 10 per cent. of paraffin wax, it should be noted that the method of estimation adopted is as follows: 2 to 3 grams of the pitch are shaken thoroughly with 250 to 300 c.c.s pentane, and allowed to stand for 24 hours; the precipitated hard asphalt is separated by filtration, and washed with pentane, dissolved in hot benzol, and estimated; the filtrate and washings contain not only the paraffin wax, but soft asphalt and other substances, which would be thrown out with the paraffin wax from the ether solution by alcohol; in order to remove these bodies and so make it possible to recover the paraffin wax in a pure condition, the filtrate is treated several times with sulphuric acid of 1·84 specific gravity until a fresh portion of the acid is but slightly coloured; the solvent is then removed and recovered by distillation, and the paraffin wax is estimated in the residue by the ether-alcohol precipitation method at – 20° C. in the usual way.

If, however, this pitch is distilled to coke as in the preliminary operation recommended by some authorities, about half of the paraffin wax appears to be broken down no matter how quickly the distillation is conducted. With the pitch under review the paraffin wax content, when the preliminary operation of distilling is resorted to, is only 4 to 5·5 per cent., as against 8 to 10 per cent. when the method first described is used. It is known that these results are the reverse of those obtained with some petroleum residual pitches, since solid paraffins may be both destroyed and formed during the process of destructive distillation. Where the constituents of a paraffin-like nature consist of ceresin as well as paraffin wax proper, more paraffin wax may be obtained in the distillate than existed in the original pitch.

The characteristics of two representative samples of this pitch are as follows:—

1. Specific gravity	1·038
Penetration at 77° F. (100 grams for 5 secs.)	78
Ductility at 77° F. (Dow)	over 100
Flowing point (Kovac's)	50° C.
Bitumen soluble in carbon disulphide	99·75%
Bitumen soluble in carbon tetrachloride	99·5%
Malthenes (soluble in pentane)	70·1%
Asphaltenes	29·65%
Free carbon and ash	0·25%
Paraffin wax (pentane method) (M.P. 104° F.)	10·59%
Paraffin wax (distillation method) (M.P. 105° F.)	5·27%
Sulphur	2·89%
The malthene extract was of a sticky cementitious nature.	
2. Specific gravity	1·047
Penetration at 77° F. (100 grams for 5 secs.)	35
Ductility at 77° F. (Dow)	42
Flowing point (Kovac's)	97° C.
Bitumen soluble in carbon disulphide	99·68%
Bitumen soluble in carbon tetrachloride	99·45%
Malthenes (soluble in pentane)	63·36%
Asphaltenes	36·32%
Free carbon and ash	0·32%
Paraffin wax (pentane method) (M.P. 104° F.)	9·7%
Paraffin wax (distillation method) (M.P. 105° F.)	4·38%
Sulphur	2·91%
The malthene extract was of a sticky cementitious nature.	

From these characteristics it will be observed that the total bitumen as revealed by the solubility in carbon disulphide and carbon tetrachloride is high, and that the proportion of malthenes (petrolenes) to asphaltenes would appear to be normal for a petroleum residual pitch. In order to ensure concordant results in the estimation of malthenes, pentane is always used by the writer as the solvent, since it is of the utmost importance that the solvent should be a pure paraffin compound and as near as possible always of the same density. With regard to the proportion of malthenes to asphaltenes which will give the best results when the pitch is

used for road-making there is much difference of opinion amongst experts. Clifford Richardson, for instance, suggests that the proportion should be three to four times as much malthenes as asphaltenes; *i.e.*, there should be 75 to 80 per cent. malthenes, whereas many petroleum pitches which have proved highly successful for road-making, when tested in the writer's laboratory, have only contained 56 to 70 per cent. malthenes soluble in pentane. Similarly with regard to physical tests there is still some difference of opinion. Moreover, the tests laid down as giving a satisfactory pitch which will be alright for one country, will not suit the climatic conditions in another. In hot countries for example it is often found desirable to sacrifice ductility to hardness, and this has been the case in Egypt. It has also been proved that for a given penetration at 77° F. those pitches which are the most susceptible to temperature changes are the most ductile at 77° F. As a matter of fact, although some authorities look upon a high ductility as of the greatest possible importance, there are some bitumens in common use to-day, and giving excellent results, whose ductility is as low as 15 cms., and even less, so that it seems evident that the correct interpretation of the ductility test is most difficult.

It would appear desirable therefore that, provided certain general principles are broadly complied with, the physical and chemical tests should not be laid down definitely to govern the manufacture of pitch to be used under any set of climatic conditions until large-scale tests have been carried out on the roads and careful observations made over fairly long periods of time. The manufacture can then be altered from time to time, until standard tests are arrived at which will suit the conditions of climate, temperature, etc. Such tests are now being carried out on the streets of Cairo with bitumen made in the Government Petroleum Refinery, Suez, from Hurghada crude oil received as royalty in kind.

So far, on the large scale, only steam-distilled bitumen is being produced, although it is believed by some authorities that air-blown bitumens are less susceptible to big temperature changes than steam-distilled products, while various American experts hold that they are tougher and less brittle than the steam-distilled bitumen, prepared from the same crude and of the same melting point. Air-blown pitches are also easier to finish than steam-distilled pitches, that is to say, they do not come to grade so rapidly, which is a decided advantage. The results with the steam-distilled product are being awaited before making any change, especially as some roads already made and painted with this bitumen would appear to be turning out quite well.

Numerous experiments have been made, however, in the laboratory on finishing by air blowing, varying both the quantity of air used and the time of blowing. These experiments had the effect

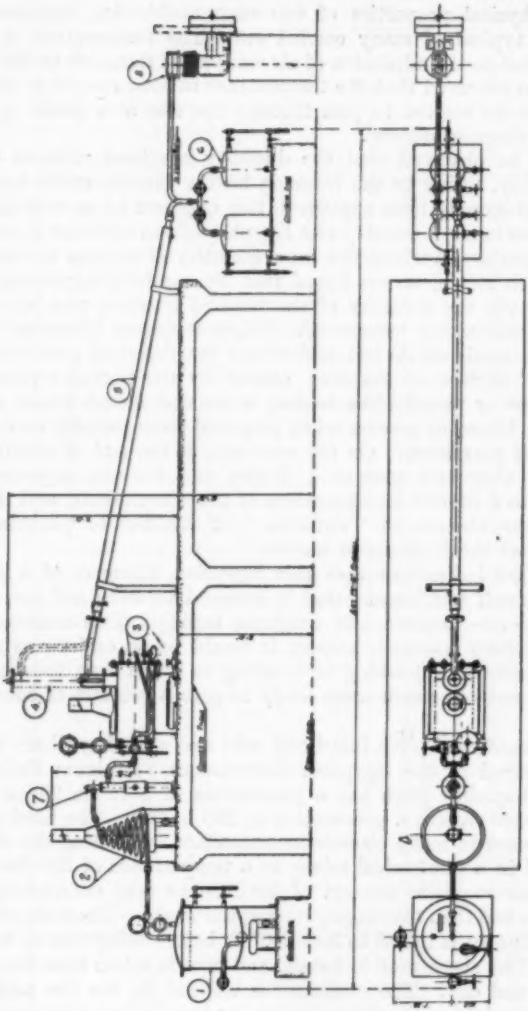
Nature of bitumen.	Cub. ft. of air blown at 230° C.	Proximate analysis.				Solubility.		Physical examination.		
		Paraffin wax.	Asphaltene.	Bitumen sol. in CS_2.	Free carbon.	Ash.	In CCl_4.	In pentane.	Penetration 100 grams 5 secs. at 77° F.	Flowing point K., ° C.	Ductility (Dows) at 77° F.
Hard, (unblown)	—	% 10·35	31·73	99·8	0·0	0·2	99·4	68·79	121·5	99·5	cms. 85
Same bitumen, 1st blowing	42 cub. ft. to 7000 grams pitch in 2 hours	7·85	32·23	99·1	0·7	0·2	98·2	67·54	49	65	65
Same bitumen, 2nd blowing	35·5 cub. ft. to 7000 grams in 2 hours	7·06	33·65	·98·8	1·0	0·2	98·0	64·8	28	68	12

of reducing ductility and hardening the bitumen, as well as reducing the paraffin wax content. The following results show the alteration in the physical properties of one such air-blowing experiment, which is typical of many carried out. The temperature of the bitumen before the admission of air was varied from 200 to 250° C., and it was observed that the temperature at once rose 10 to 15° C. as soon as air started to pass through the still as a result of the chemical changes induced.

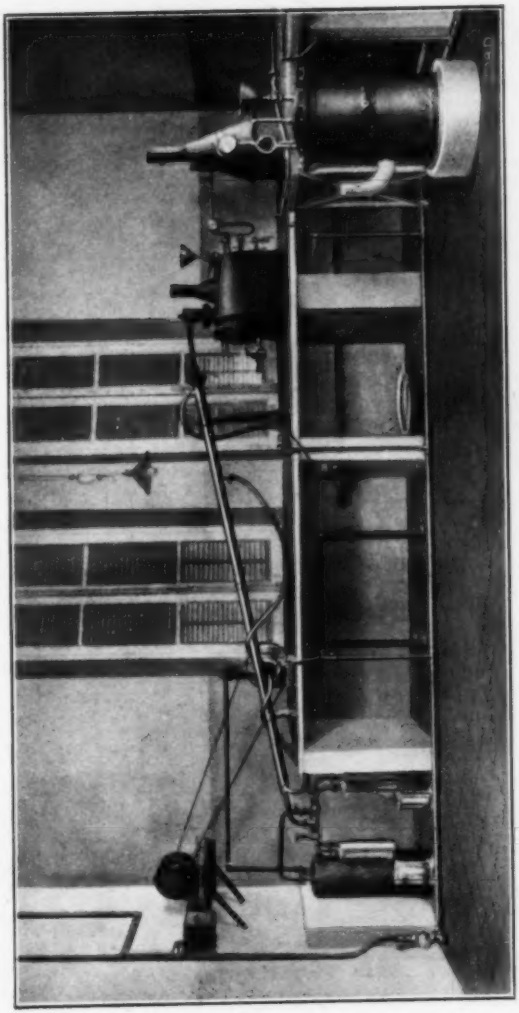
It will be observed that the ductility has been reduced very considerably, owing to the bitumen having become much harder, but as has already been explained, this may not be so very disadvantageous in a hot country like Egypt, while in any case in subsequent experiments where the same quantity of air was blown but mixed with steam, it was found that by carefully regulating the steam supply the ductility of the finished bitumen was 50 cms., and the penetration became 38. These air-blown bitumens from Hurghada crude oil do not suffer from the defect of presenting a "greasy" surface on standing, caused by the partial separation of vaseline or paraffin-like bodies, a decided defect which some air-blown bitumens possess when prepared from paraffin or mixed base crude petroleum. On the contrary, at the end of months of standing, they still present a bright and lustrous appearance, pointing to a perfect amalgamation of the constituents, and therefore to the absence of "sweating" of vaseline or paraffin-like bodies from the bituminous matrix.

There are indications that this Egyptian bitumen, of a given penetration, if weathered—that is, exposed to wind and sun in a shallow pond—hardens and toughens rapidly. This tendency is being carefully watched, because it would be an easier and more certain method of finishing or bringing to grade than finishing in the still, and one much more likely to give a product of constant quality.

Two qualities of pitch (hard and soft) and a fluxing oil are being manufactured at the Egyptian Government Petroleum Refinery. The hard quality pitch has a penetration of between 20 and 30, and the soft variety a penetration of 200 to 250. The hard pitch is being used to make bituminous macadam by heating the stones and sand in a mechanical mixer to a temperature of 250–300° F., adding the requisite amount of bitumen to coat completely the aggregate and then thoroughly mixing the whole. The temperature of the bitumen is raised to 300–350° F. before being run on to the stones. The stone used is basalt, and care is taken that the sand is clean and dry. The macadam is wheeled to the site and laid to a depth of 3 inches whilst still hot, and well rolled with an eight-ton roller to the desired contour. The gauge of the aggregate hitherto used has been one to three inches, but in future better



VACUUM DISTILLATION PLANT USED BY THE AUTHOR.



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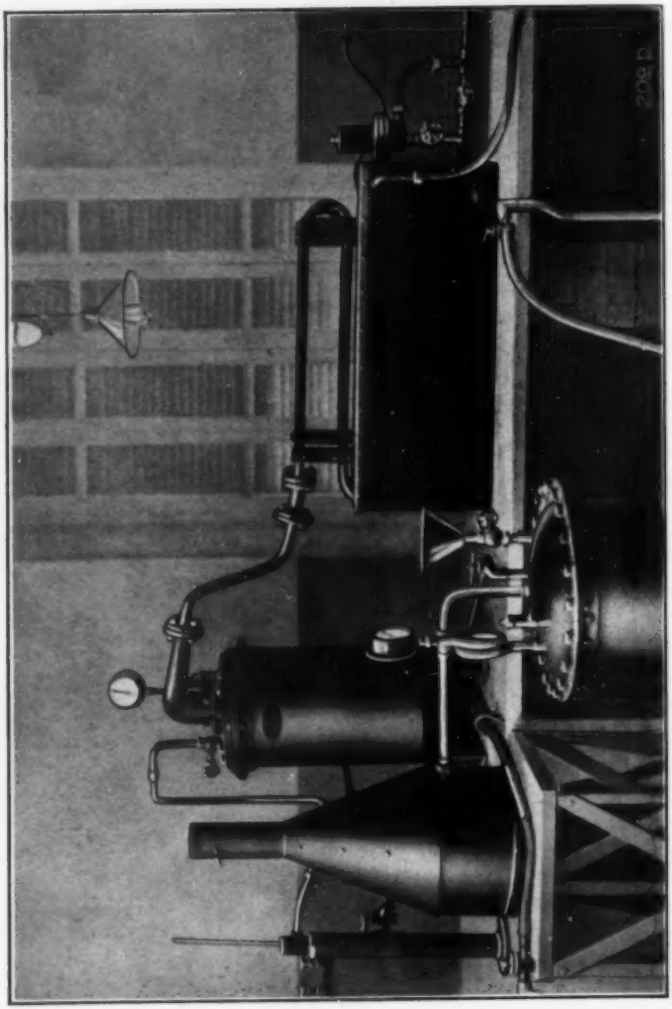

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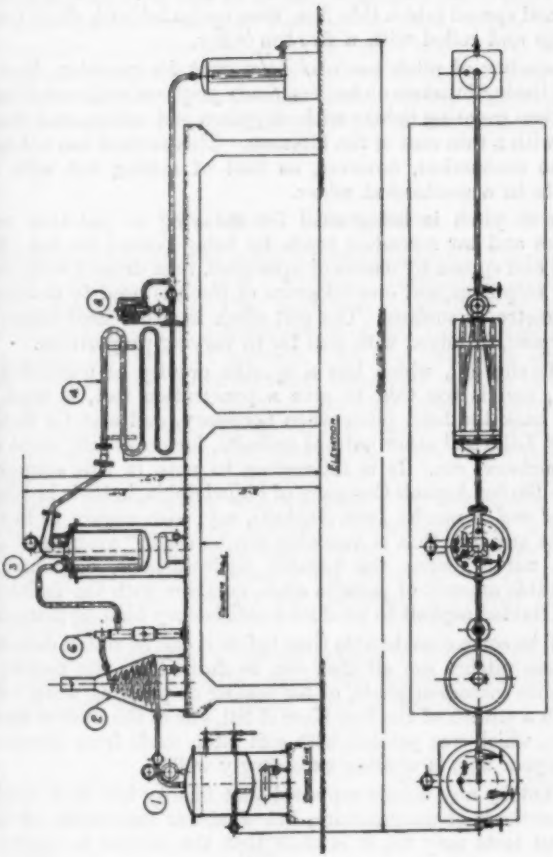

PRESSURE DISTILLATION PLANT USED BY THE AUTHOR.

PRESSURE DISTILLATION PLANT USED BY THE AUTHOR.

grading will be ensured by using a stone crusher and bringing the stone down to one inch. Fifty-five kilograms of bitumen is used per cubic metre of stone (one cubic metre of stone weighing one and a half tons). A sealing coat of bitumen is always applied, ten kilograms covering one square metre of surface. This is poured on hot and spread into a thin film, then sprinkled with clean basalt chippings and rolled with a five-ton roller.

This quality of pitch has also been used for grouting, that is, pouring the hot bitumen on to the already prepared and consolidated metal, then covering lightly with chippings and rolling, and finally sealing with a thin coat of the bitumen. This method has not been found so economical, however, as that of mixing hot with the aggregate in a mechanical mixer.

The soft pitch is being used for spraying or painting worn macadam and tar macadam roads by being poured on hot (300-350° F.) and spread by means of squeegees, then dressed with clean sand or chippings, and one kilogram of pitch is used to cover one square metre of surface. The soft pitch is either used alone for this purpose, or mixed with coal tar in varying proportions.

The fluxing oil, which has a specific gravity of 0·980–985 at 15·5° C., and is too thin to give a penetration test, is used for cutting back the hard pitch when necessary, and also for fluxing Trinidad Lake and other natural asphalts, for preserving wood and metal surfaces, etc. It is interesting to note in this connexion that the Barber Asphalt Company of Philadelphia, in their brochure, *Trinidad and Bermudez Lake Asphalts*, say, with respect to fluxing oils, that any flux that is available can be used, "even those of a paraffin nature, since the paraffin hydrocarbons, containing a considerable amount of paraffin scale, combine with the malthenes of the Trinidad asphalt to produce a satisfactory binding material."

It will be some considerable time before it can be stated definitely that these pitches are all that can be desired for the making of bituminous macadam roads, or for sealing or painting worn roads, although a stretch of the Rue Kasr el Nil, one of the busiest streets in Cairo, which was painted with soft pitch made from Hurghada crude a year ago, is wearing exceedingly well.

It is not by any means supposed that finality has been reached in the methods of manufacture, but whatever the results of these first road tests may be, it is clear that the subject is worthy of much time and study on the part of the Egyptian Government, especially when there is a strong possibility of eventually manufacturing a first-class pitch for road-making from indigenous crude oil. Every effort will be made to bring this to a successful conclusion rather than import into Egypt large quantities of bitumen at high prices from such far off countries as Mexico and the Island of

Trinidad. There is still a good deal to be done in the development of main roads of communication in Egypt, and it is highly probable that if a cheap indigenous bitumen could be supplied in sufficient quantity, the making of good roads would be directly encouraged.

Research work on this oil is being developed on a large scale in the Government Petroleum Refinery at Suez, which has been working for some time past on royalty oil. The general scheme of operations being carried out is as outlined above, but is necessarily modified from time to time to meet, on more or less commercial lines, the requirements in petroleum products of Government Departments.

"Cracking" Distillation.

Before leaving this side of the subject it may be of some interest to give a typical result of a "cracking" distillation of the heavy residue conducted under the moderate pressure of 30–35 lbs. to the square inch, and at a temperature of 360° C. The aim here was to produce benzine and kerosene from the residue, in accordance with what is, after all, a common industrial practice in America and other oil countries to-day. The still and condenser was of such a design that not only the oil and vapour in the still, but the condensate in the condensor worm was kept under the desired pressure by means of a valve, fitted on to the worm end, with a projecting spindle which was weighted. By this means the loss through gasification was reduced enormously, the condensate under pressure appearing to take up gases, which, if they had been allowed to escape in the ordinary way, would have been uncondensable, or in other words, the reaction appeared to be a reversible one.

The residue used had a specific gravity of 0·974 at 15·5° C., and had been denuded of all its benzine and kerosene by distillation in the ordinary way. The results were as follow:—

	%	Sp. gr. at 15·5° C.	Flash point.
"Cracked" oil	70·0	0·852	Below 40° F.
Coke	23·1		
Loss (by gasification) ..	6·9		
Total	100·0		

When this distillate was cooled to −20° C. it remained quite fluid, and its cold test was 5° C.; *i.e.*, when allowed to warm up again it ceased to show any signs of paraffin wax at the latter temperature.

Its composition, as shown by fractional distillation, was as follows:—

	%	Sp. gr.	Flash point. °F.	Viscosity (Redwood) at 60° F. Secs.	Viscosity (Redwood) at 100° F Secs.
Light petroleum spirit	6·5	0·719			
Heavy petroleum spirit	3·9	0·768			
Kerosene distillate	23·6	0·820	98		
Heavy kerosene distillate	28·9	0·858	190		
Diesel fuel oil	36·5	0·890	276	85	45
Loss (gas)	0·6				
Total	100·0				

Combining these two sets of figures the results, calculated as percentages of the residue, would be:—

	%	Sp. gr.	Flash-point. °F.	Viscosity (Redwood) at 60 F. Secs.	Viscosity (Redwood) at 100° F. Secs.
Light petroleum spirit	4·5	0·719			
Heavy petroleum spirit	2·7	0·768			
Kerosene distillate	16·5	0·820	98		
Heavy distillate	20·2	0·858	190		
Diesel fuel oil	25·6	0·890	276	85	45
Coke	23·1				
Loss (gas)	7·4				
Total	100·0				

In actual practice, if this method of refining were to be adopted, the large percentage of coke would not be made, but pitch would be manufactured as the residue in the first distillation and the heavy oil and paraffin distillate would be the product to undergo the subsequent "cracking" pressure distillation.

Paraffin Wax Extraction.

There remains to consider a possible alternative method of refining, namely, by the extraction of the paraffin wax and the manufacture of lubricating oil. Several schemes have been tried. It was found that the paraffin wax is present in the amorphous condition of proto-paraffin—as, in fact, it no doubt exists in all crude oils—and it was somewhat difficult to convert it into the crystalline form of pyro-paraffin, in which condition it is easily freed from oil by pressure at low temperature. Experiment showed that by one distillation only down to coke or hard pitch, the paraffin distillate was not yet in a condition for cold pressing, even when cooled to very low temperatures, the whole simply being converted into a gelatinous mass. By redistilling the paraffin wax distillate,

however, using superheated steam, better results were obtained, although the resulting crude paraffin scale was inclined to be blackish, and consequently, somewhat difficult to refine to a white wax.

The carrying out of the following scheme, however, gave most satisfactory results. The crude oil was distilled down to coke, and the benzine was separated, but the whole of the rest of the condensate was run together, the kerosene being left in to thin the distillate for a subsequent chemical treatment. The specific gravity of the distillate was 0·878 at 15·5° C., and the yield 76·5 per cent. It was separated from water and then thoroughly shaken with 3 per cent. conc. sulphuric acid (sp. gr. 1·84) for one hour, the temperature of the oil being only high enough to ensure that it remained quite liquid. It was then allowed to settle and the black acid tar run off. The tar free oil was then treated for twenty minutes with an excess of caustic soda solution (1·34 sp. gr.), the soda tar settled and run off. The loss on treatment was 2·9 per cent., and the specific gravity of the oil was 0·8735 at 15·5° C. The treated oil was now redistilled with the assistance of superheated steam and the kerosene taken off in the usual way; 15 to 16 per cent. of an intermediate or solar oil was then collected, but as soon as a drop of the condensate showed signs of solidification, when placed on the outside of a beaker containing ice, the receiver was changed, and the rest of the distillate, excepting a very small quantity (0·3 per cent.) at the end, which had a dark red colour, and which would have spoiled the subsequent cold pressing operation, was run together for heavy oil and paraffin. The effect of the acid treatment before this distillation was here very evident, since the heavy oil and paraffin distillate had a beautiful golden yellow colour. The intermediate or solar oil which came off before the heavy oil and paraffin distillate, and which amounted to 16·5 per cent., had a specific gravity of 0·852, a flashpoint of 159° F. and a viscosity in Redwood's No. 2 Viscometer at 32° F. of 169 seconds. The wax distillate was now very slowly cooled, first by running water, and finally by cold brine, and then passed through a paraffin filter press, the temperature of the circulating brine being kept at – 13°C. As the pressure rose in the filter press, the expressed oil came off in a continuous stream. The resulting crude paraffin scale was an excellent dry flaky product (melting point 117° F.), which, after "sweating" away the entrained oil and treated with animal charcoal, yielded a pure white paraffin wax having a melting point of 122° F.

The yield of crude paraffin scale was only 6 per cent., however, which compares unfavourably with the paraffin wax content of the crude oil, but the difference is due to the loss through "cracking" in the two distillations necessary to convert the wax to the crystalline condition.

The filtrate or squeezings (lubricating oil base) from the paraffin pressing, and amounting to 30 per cent. on the crude oil, had the following characteristics :—

Sp. gr. at 15·5° C.	0·916
Flashpoint (Pensky-Marten)	250° F.
Viscosity (Redwood No. 1) at 60° F.	200 secs.
Viscosity (Redwood No. 1) at 100° F.	92 secs.
Cold test	26° F.

This oil on concentration by means of superheated steam yielded 7·8 per cent. of thin intermediate oil having a specific gravity at 15·5° C. of 0·879, which was mixed with the solar oil from a previous distillation. The concentrated lubricating oil had the following characteristics :—

Sp. gr. at 15·5° C.	0·924
Flashpoint	356° F.
Viscosity (Redwood No. 1) at 100° F.	470 secs.
Viscosity (Redwood No. 1) at 200° F.	63 secs.
Cold test	28° F.

The general result of this scheme of refining was as under :—

	%	Sp. gr. at 15·5° C.	Flashpoint (close test). ° F.
Benzine	8·0	0·731	
Kerosene	15·0	0·822	108
Solar oil	24·3	0·860	170
Unfinished lubricating oil	23·0	0·924	356
Crude paraffin scale	6·0		
Coke	12·2		
Loss	11·5		
	100·0		

The high loss is principally due to gasification in the distillations to coke, but on the large scale this gas would not be lost, but would be burnt under the steam boilers, or otherwise recovered. The loss through gasification could also be avoided to a large extent by stopping the still at hard pitch instead of distilling to coke, although this would have the effect of reducing the yield of crude paraffin scale. On the other hand, pitch would be a more valuable product than coke.

The analysis of a typical sample of the still coke was as follows :—

	%
Carbon	96·76
Sulphur	2·96
Ash	0·28
	100 0

Jemsa Crude Oil.

Although this paper is concerned with the Heavy Grade Crude Petroleum found at Hurghada, it is probably desirable that some mention should be made of the high-class light paraffin base oil which has been found at Jemsa, also situated on the western shore of the Gulf of Suez, and some thirty miles north of Hurghada. The first oil was struck here in 1908 at a depth of 1290 feet, and since that time the field has produced 179,402 English tons, but now, unfortunately, the production is very poor indeed, being only about 3000 tons per annum. The characteristics of this light oil are as follows :—

Sp. gr. at 15·5° C.	0·827
Colour	Dark greenish brown
Sulphur	0·65%
Asphalt	0·63%
Paraffin wax (M.P. 116° F.)	4·94%

and the commercial products obtained by fractional distillation as are follows :—

	%	Sp. gr. at 15·5° C.	Flash-point (close test). ° F.	Viscosity (Redwood) at 100° F. Secs.
Light benzine	19·54	0·7193		
Heavy benzine	7·47	0·7698		
Kerosene	32·43	0·8187	116	
Residue	39·82	0·9014	290	212
Loss	0·74			
	100·00			

From which it will be seen that this oil is of a very different variety from that produced at Hurghada, being as nearly as possible a paraffin base petroleum.

Abu Durba Crude Oil.

The oil so far produced from the small field of Abu Durba, situated on the eastern shore of the Gulf of Suez, is of a heavy asphaltic nature, containing varying proportions of a waxy resin, which indicates that the oil is an inspissated and oxygenated product of petroleum.

It has the following characteristics :—

Sp. gr. at 15·5° C.	0·945/960
Flashpoint (close test)	Over 100° F.
Viscosity (Redwood No. 1) at 100° F.	3000 secs.
Sulphur	2·35%
Hard asphalt	10·5%
Waxy resin	5/6%
Distilling below 290° C. (approximately)	20%
Sp. gr. of the distillate	0·860 at 5·5° C.

In conclusion, I would like to acknowledge the valuable assistance given to me in carrying out this work by my colleagues, Mr. A. Lucas, until the beginning of the year Director of the Chemical Department in Cairo, Dr. A. G. Guinness, the present Director of the Department, Mr. R. H. Findlater, Manager of the Government Petroleum Refinery, and my assistants in the Petroleum Research Laboratory, Mr. C. W. Wood and Mr. W. H. Crouch.

DISCUSSION.

The President said he was sure the Institution was greatly indebted to Mr. Guthrie for the very interesting paper he had supplied. It was a paper full of information and reference to the properties of Egyptian crude oil, and no doubt would lead to a valuable discussion.

Dr. A. E. Dunstan said it had been a very great pleasure to listen to so authoritative and concise an account of the properties of a very typical crude oil, and the members were very much indebted to the author, and to Prof. Brame, for a very admirable survey of a particularly intricate subject. It was the second paper on crude oils that had been read at the Institution in the past nine years. Mr. Kewley* had given an account of the chemistry of Borneo oils two years ago, and it might be as well at the present moment to emphasise the importance of a series of papers on the different crude oils of the world. One thing was certain, that before very long many of those crude oils would not be available for examination. He remembered some short time ago proposing to the Council that they should take some underground storage and lay up for posterity barrel samples of the chief producing fields, because until a definite technique had been established for the examination of those oils there would be very little further progress. That brought him to the first paragraph of the paper in which the author emphasized the importance of research and investigation on the raw materials. It was an astonishing thing that pure science had always lagged behind the technical development of an industry. There were very few examples one could think of in which the theoretically-minded and academic type of man had, so to speak, laid the foundations of an industry. As a rule the despised technical man came first, and the theorist followed behind him and explained what the other man had been doing. That was not as it should be. There was a vast scope for a thorough

* "The Crude Oils of Borneo." J. Kewley. *Jour. Inst. Petr. Techn.*, VII., No. 27, July, 1921.

and complete investigation into the properties, physical and chemical, in every raw material, and in the rush of development necessary for output, the majority of these important properties were not adequately examined. That was all the more reason why now oil chemists should set before them the difficult, almost impossible, task of developing a technique which would enable the components of the crude oil to be isolated, identified, and examined. It was a well-known fact that outside the range of the first 150° of boiling point there was a most lamentable ignorance of the compounds present. Mr. Guthrie had referred to that in his paper. Not only was there need for investigation into the nature of the products themselves, but, of course, there was a vast need for investigation into the methods of handling those products. It was very surprising how few new refining methods had been developed and how the old acid and soda treatment had persisted. He mentioned particularly the work of Edeleanu as an instance of a far-reaching new method of separating petroleum products, a method based on solution rather than one of distillation. When one started heating and distilling an oil there was no knowing what one would get out of it, but what was got out of it was frequently not in the original material. The paper was much too comprehensive to be discussed in detail, but he should like to indicate one or two points that had interested him personally. On page 214 the author pointed out that vanadium and nickel were obtained in the ash of Egyptian oil. It was a most extraordinary thing, and a matter that he thought would be rather far-reaching, that oils so different, South American oils, Mexican oils, Egyptian oils and Persian oils, all contained vanadium and nickel. In a recent examination of the ash of Persian oil 4 per cent. of vanadium and 2 per cent. of nickel were discovered. It was a most striking thing that that vanadium should be present. Whether his friend, Dr. Dvorkowitz, would be able to use that fact as further evidence for the Mendeléeff theory he did not know. Mr. Guthrie also referred to distillation under a vacuum of 28 inches, a very moderate vacuum. Probably with a very high vacuum he would have got still better results. There was a reference to the confusion between terms benzine and benzene by the reader of the paper, but perhaps a better word to use to avoid mistakes would be gasoline. On page 217 the author mentioned the residue from the topped oil as being semi-solid at low temperatures. No doubt, Mr. Guthrie would be able to answer any questions put to him through the Journal, and therefore he should like to ask whether those residues of topped oil showed any viscosity hysteresis effects. The cracking described on page 218 was a well-known practice. He was rather surprised that the author did not attempt to crack his topped oil right away under more or less well-known conditions, such as a pressure of 200 or

300 lbs., and a temperature of 400 or 500° C. rather than go to the trouble of isolating the pitch first, although he appeared to have a market for pitch when it was produced. The selective cracking of paraffin was an interesting point described by the author and many people had carried it out. Very few people, however, went to the trouble of acknowledging the pioneer work of Thorpe and Young, work which was done about fifty years ago, in which paraffin wax was cracked, and more readily so than any other constituents of mineral oil.

Mr. A. Beeby Thompson said that Mr. Guthrie was essentially engaged in endeavouring to produce certain products that the Government needed at the time, and he had really attempted to obtain more of the heavy than the light products. One of the most interesting suggestions in the paper, to which only brief allusion was made, was the value of analyses in tracing the origin of oil, or, at any rate, in indicating its probable source so that one could judge whether oils were indigenous or adventitious. It had always been hoped that analyses would be able to help very much in that direction, and geologists had always looked to chemists for guidance. In Egypt the problem of origin was particularly obscure, because in the Miocene beds there occurred a comparatively light oil, sp. gr. 0.830 or thereabouts, and even where seepages occurred in the Miocene beds the same light densities prevailed, but in the Cretaceous rocks heavy oils of 0.920 to 0.925 sp. gr. were found. At Abu Durba wells had been sunk in beds of doubtful age derived from the disintegration of neighbouring igneous masses ; the beds were very largely sands composed of igneous fragments, so that the contained oil to which reference had been made by the author was almost certainly an oxidised and polymerised product derived from neighbouring Cretaceous strata impregnated with oil. The Egyptian oil problem at the present moment was attracting special attention, for apart from determining whether the oil was derived from Miocene or Cretaceous rocks, or both, the influence of structure and migration on the character of the oils is unknown. A number of recent wells have been sunk on the apices of domes, and crests of anticlines which have penetrated great thicknesses of rock salt, often exhibiting indications of oil. It is now realised that the flanks of these domes and anticlines may present favourable conditions for the accumulation of oil as in Louisiana, Rumania and elsewhere. Had we known as much about the effect of environment on oil and the changes caused by migration it might have been possible to say from the samples collected whether the oil was indigenous to the salt or a product of migration from nearby beds.

Mr. Guthrie's paper is valuable in showing how a so-called low-grade, mixed-base crude oil can be treated to yield a wide range

of marketable products if and when market conditions favour their manufacture.

Mr. D. A. Sutherland said it was very interesting to learn from the different grades of oil in different countries as to the possibility of drilling and finding oil. He had noticed several figures given in the earlier books on Jemsa oil, figures such as specific gravities 0.908 and 0.903 and, in the sample examined by Sir Boverton Redwood, 0.905. Jemsa oil is given by the author as somewhere about 0.827, which was very much like oil obtained at that place twelve years ago. It was his privilege in 1906 to examine the oil fields at Jemsa, where work had ceased for twenty years; when some five or six wells had been drilled. From an examination of the seepage oils, corresponding to the analysis in the paper, he saw that the formation around carried a great deal of free sulphur. It was surprising to him to find lighter oil below. He had something like 1000 tons a day from the first well, and a number of wells were subsequently drilled. The production later was nearly 200,000 tons of oil from the field of Jemsa. Had they been able to find an oil such as that at Hurghada, thick heavy oil, work would have developed straight away, but the much lighter oil which justified refining led to delays in development. A point he further desired to make was in connexion with the different grades of oil found at Hurghada. They were what Dr. Dunstan referred to in discussing Mr. Kewley's paper on Borneo, when it was pointed out that asphaltic oils were found nearer the surface, and subsequently in a lower geological formation there were lighter oils, and below those again paraffin base oils. As Mr. Guthrie had pointed out, the oil at Hurghada was apparently geologically deeper than the lighter oils at Jemsa. There was no doubt that the publication of analyses and details, the geological formation in which the oil was found must be of very great value. In time the co-ordination of results would lead to developments that had not previously been looked for. Dr. Dunstan had already made a point that he had intended to refer to, the presence of vanadium. Vanadium occurred to the extent of 43 per cent. in the ash of asphalt found in the Andes, somewhat north of Lima. He had had occasion to examine it about two years' ago, and it was a very curious matter that the vanadium should occur. There it was, very highly concentrated, and there might be something in the point Dr. Dunstan had made. He did not know whether there was any nickel present, being more interested in the presence of vanadium.

Dr. Dunstan asked whether nickel occurred in the Pennsylvania oilfields.

Mr. Sutherland said, No. The asphaltic distillation yielded a very high percentage of oil. The vanadium content was so high

that it was to the value of nearly £2 on the asphalt. He should have liked very much to have spoken at some length on the question of bitumen, as he had from time to time given a good deal of attention to the subject, but he might send some further notes on that in writing.

Mr. E. Lawson Lomax said that junior students might take the paper as a model on which they could work on the examination of crude oils. If more results of similar examinations could be published it would enable a wide knowledge to be obtained of the crude oils of the world. On page 216 the author, in talking of the benzine and kerosene fractions, said that the benzine was not entirely free from sulphur compounds (0.015 per cent. sulphur, determined by the lamp method). The sulphur content of the pitch was about 2.9 per cent., and the sulphur content of the original crude about 2.25 per cent. The figures did not altogether fit in. One usually expected the sulphur to be concentrated in the heavier residues, obtaining a larger percentage of sulphur in the residues than in the crude oil, and an increase in sulphur content from the lighter boiling fractions up to the heavier ones. He took it the author was referring to the finished benzine, and he should like to know if that was the case. As to the low content of sulphur in the pitch, taking a crude oil that had roughly 1 per cent. of sulphur in it, and taking off about 30 per cent. of distillate from this, the residue would contain about 1½ per cent. of sulphur, and taking off 60 per cent., the residue would be about 3 per cent. of sulphur, whereas the percentage of sulphur in the pitch with this particular oil did not seem to progress so rapidly as in most crude oils. With regard to the manufacture of pitch, the author had evidently had his hands tied by the Government requirements, but it would be useful to know whether he had thought of the commercial side of the production of pitch. The total production of that field was about 3500 tons of crude oil per week, and with 29 per cent. of pitch it was equivalent to about 1000 tons of pitch per week, and he was wondering whether Egypt had a market sufficiently large for that. On the question of the wax, it seemed to him that the wax was such a valuable product all over the world that it was much better and wiser to make more wax than to make pitch. With respect to the fuel oil mixtures, he should like to know whether there was any separation of bitumen on standing. By running down the heavy residues and thinning them with lighter oils, which were not very good solvents for the bitumens, there would probably be separation from Sample C. With respect to the quality of the pitch, he quite agreed with the author that no two countries required the same type of pitch; hot countries required a different type from cold countries. In countries where

there were heavy frosts the requirements of the various kinds of asphalt were different.

Mr. W. J. Wilson expressed his admiration of the manner in which Mr. Guthrie had carried out his investigation. The section on extraction of paraffin wax was one of particular interest. The facility with which wax could be separated from distillates from different oils varied. In some cases the distillate was of such a crystalline character that separation by filtration was extremely simple; in other cases the distillate was so amorphous that however carefully the distillation was conducted it was practically impossible to filter it. That did not seem to depend on the proportion of paraffin in the distillate, nor upon its character as regards melting point. It might possibly have some connexion with the content of asphaltic or resinous bodies, though in some cases an oil which contained a proportion of these would produce a paraffin distillate which was quite readily filtered. It was rather surprising that Mr. Guthrie, who had obtained such good results from vacuum distillation, did not apparently apply that method to his experimental effort to produce a paraffin extraction. Personally he felt that for extraction of paraffin and lubricating oils no form of distillation was to be compared with a good vacuum distillation. The method which Mr. Guthrie used, namely, treatment by 3 per cent. of acid followed by redistillation, would be rather a costly one, and probably he would obtain better results by a simple vacuum distillation. There was a good deal of evidence to show that the use of super-heated steam in the distillation of heavy oils tended to produce a distillate which would not readily filter owing to the production of an amorphous product, whereas if the steam was reduced considerably in quantity, or even omitted altogether, the product was much more crystalline and readily filtered.

In connexion with the chemical examination of the oil the content of aromatic hydrocarbons in the first 30 per cent. of the crude oil was referred to. According to the analysis that 30 per cent. ran well into the kerosene and perhaps even beyond it, as well as including the petrol hydrocarbons. Mr. Guthrie stated that his analysis was performed by the method of Tizard and Marshall, but the speaker believed that those authors regarded their method as applicable only to substances boiling below 150° C., and the same limitation was applicable to the method of Dr. Thole. If the author had found a means whereby the aromatic hydrocarbons could be accurately determined in bodies of a higher boiling point, it would be of great value to the analysis of higher hydrocarbons.

Sir F. W. Black said he desired to ask him one small question as to details of his method in taking the flowing point referred to on page 220. He noticed that the temperatures mentioned for

the flowing points seemed to have a relation to the percentages of asphalt, but very little relation to the number of seconds on the Redwood Viscometer. He was very glad to find an ally in Mr. Guthrie in regard to what he thought was a little undue modesty on the part of the Standardisation Committee of the Institution in not giving a test for asphalt percentages for Diesel oils. If the Standardisation Committee did not feel able to give a pronouncement as to permissible percentages of asphalt in oils for Diesel engines, he could not quite see, and he thought Mr. Guthrie felt the same, why they should not at least give the standard tests for the percentages which were usually regarded by experts as permissible. It was very satisfactory to find a chemist, whilst giving results of an actual scientific nature, also bearing in mind the point of view of those who had to sell or use oil. That was one of the extremely valuable points in Mr. Guthrie's paper and investigations—*viz.*, that he had kept the commercial standpoint in view all the time.

Mr. Gordon Pitt said he had found the paper of particular interest, inasmuch as, while dealing with the matter in an extremely scientific manner, it was at the same time examining an oil from a particularly wide point of view. Mr. Guthrie's special reasons were due to the fact that he was placed in a somewhat unusual position, having to deal with an oil of local origin for, practically speaking, a local market, and presumably in quantities which would not have justified treatment for export. That made the paper in some ways technically more interesting. To find a properly conducted investigation into the value of the bituminous element in an oil as a road-making material was an interesting thing. There was no doubt that many of the asphaltic oils had a very important use in that direction, a use which was known to the people who had to sell it, and it was that question which deserved close scientific and careful investigation, and it was a very useful thing that Mr. Guthrie had at some length dealt with that point. Mr. Guthrie's whole scheme of refining seemed to him to be based on very broad and wide lines. In producing the pitch that his immediate superiors wanted, he also produced, as part of the same refining process, the remarkably light cracked or semi-cracked condensate which, when blended with his difficult and more or less useless heavier viscous residue, produced an admirable fuel oil useful for different purposes, according to the proportions blended.

Professor Brame said he did not feel capable of shouldering the responsibility of replying to the discussion which had been raised. Sir Frederick Black had referred to one matter in connexion with asphalt percentages and a sin of omission probably on the

part of one of the Standardisation Committees. As he was personally responsible for not specifying the percentage of asphalt permissible in a Diesel engine fuel, he might give an explanation. The drafting of specifications was not part of the job of the Standardisation Committee; it was their function to specify tests, leaving it to another Committee, which had been appointed by the British Engineering Standards Association, to lay down the specification limits for the different constituents. It was very difficult to lay down any limit; whether it should be 30 per cent. of asphalt or 15 per cent. Nobody wanted it there at all, and would certainly always be without it if they could. He was very much surprised at the paragraph in the paper where Mr. Guthrie said: "This Diesel distillate was obviously too good for practical use in the climatic conditions of Egypt." It was the only place where it would be considered too good.

The President proposed a hearty vote of thanks to Mr. Guthrie for his paper, and also to Prof. Brame for reading it.

The meeting then closed.

Mr. James Kewley subsequently wrote:—

The author states that in the first six fractions from a vacuum distillation, amounting to 30 per cent. of the crude, there is an average of 16 per cent. of aromatic hydrocarbons. The Tizard-Marshall method for the determination of aromatics has only been worked out for hydrocarbons with boiling points up to about 150° C. A fraction of 30 per cent. of this Hurghada crude must have contained components of boiling point over 300° C., as the benzine and kerosene content only amount to 23 per cent. I do not think, therefore, that the 16 per cent. given as aromatic content can be accepted as in any way accurate. He states also that naphthenes are present only in very small amount in the 30 per cent. fraction. In this case, too, it is difficult to speak with any degree of certainty. A consideration of the specific gravities of kerosenes (150–290° cut) of various crude oils would lead one to consider that the oil was by no means poor in naphthenes, due consideration being given to the fact that the aromatics are not as high as stated.

The writer submits that it is only in the benzine fractions that one can speak with any confidence as to the aromatic and naphthene content. He has found the aromatic content about 11 per cent. and the naphthene content about 23 per cent.

In connexion with the residual products of distillation, would it not be better to term these asphalts, and confine the use of the word pitch to products not originating from petroleum?

The author puts forward the opinion that the presence of paraffin wax in an asphalt for road-making purposes should be an advantage, and quotes Abraham to the effect that "the determination of paraffin wax is therefore only of value for the purposes of identification." Abraham, however, also states: "Mixed base residual oils are not regarded as equal to asphaltic residual oils." The percentage of wax is not, however, unduly high. The writer has found 7 per cent., a figure which agrees with that given by the author.

Interesting possibilities for working up Hurghada crude have been studied from the chemical standpoint; their application naturally depends in the first place on various economic considerations.

Mr. T. Dewhurst wrote as follows:—

Mr. Guthrie's reference to the presence of vanadium and nickel in Hurghada crude elicited from Dr. Dunstan the information that these elements have been found in Persian crude and also in an oil from South America. Mr. Sutherland referred to a Peruvian asphalt which contains a very high percentage of vanadium. It was even suggested that further chemical research might show that these and similar facts are in some way related to the genesis of petroleum.

The writer would suggest that extreme caution is necessary in studying the relationship of these elements to petroleum. Traces of many elements have been found in various crudes. For example, Mr. J. E. Hackford, in his paper on "The Significance of the Interpretation of the Chemical Analyses of Seepages,"* stated that silica, vanadium, nickel, tin, lead, calcium, magnesium, iron, aluminium, sodium, titanium, and gold are present in the ash of the crude oil of Mexico. Further work may therefore show that a number of elements are usually associated with petroleum, and that no special significance can be attached to the occurrence of vanadium and nickel. A further point is that although vanadium is usually regarded as a rare element, it is widely diffused in nature, and its presence in petroleum may therefore be purely fortuitous. The important evidence that is required is not that vanadium occurs in petroleum, but that it occurs in quantities which are unlikely to be due to coincidence. This latter possibility is worthy of serious investigation, and may yet become an established fact.

In the small brochure on vanadium published by the Imperial Mineral Resources Bureau it is stated that "an important and interesting fact about the occurrence of vanadium is its frequent

* *Jour. Inst. Petr. Techn.*, VIII., No. 31, April, 1922.

presence in quite appreciable amounts as a constituent of carbonaceous materials such as coals and asphalts, the ashes of which sometimes contain 30 per cent. or more of vanadic oxide." In the description of the Minasragra deposit of patronite, from which the world's supply of vanadium is chiefly obtained, it is stated that "it was originally supposed to consist of coal, but the large amount of sulphur present interfered with its use as a fuel. The ore is carbonaceous, and is associated with vanadiferous asphalt." The vanadiferous asphalt deposits of Peru are extensive, and several attempts have been made to exploit them as a source of vanadium.

Vanadium also occurs in oil-shales. In the well-known Geological Survey memoir on "The Oil Shales of the Lothians," reference is made to the ash of the richest Joadja Creek Shale, and it is stated that "vanadic oxide was found by Mingaye 0.01 per cent. In the ash of Scotch shale as much as 0.12 per cent. has been found."

Vanadium is reported to be present to the extent of 2 per cent. of vanadic oxide in the ash obtained by burning the lignite that occurs in the Warkalli beds in Travancore.

F. W. Clarke, in the fourth edition of his valuable work, "Data of Geo-Chemistry," gives striking examples of the occurrence of vanadium. He states that "a still more remarkable occurrence of vanadium was noted by J. J. Kyle in a lignite from San Rafael, Province of Mendoza, Argentina. The coal yielded only 0.63 per cent. of ash, but the latter, upon analysis, was found to contain 38.22 per cent. of V_2O_5, together with silicates and sulphates of other metals. In a similar coal, probably from the same region, A. Mourlot obtained 38.5 per cent. of V_2O_5 from the ash; and in another from Yauli, Peru, Torrico y Meca discovered 38 per cent. The ash of a grahamite from near Page, Oklahoma, analysed in the laboratory of the United States Geological Survey by R. C. Wells, contained 12.2 per cent. of V_2O_5. In the ash of an asphalt from Nevada the same chemist found nearly 30 per cent., and in the ash of Trinidad manjak B. Salkover found 0.52 per cent. of vanadium."

It seems to be established that vanadium is particularly associated with certain lignites, asphalts and allied substances, and in quantities much too great to be explained merely by reference to the wide diffusion of the element. Its presence in asphalt, grahamite manjak and oil-shales, suggests that it may also be found to occur in petroleum in quantities which cannot be explained by coincidence. Should this prove to be the case, vanadium will be known to be associated with a peculiar group of substances, and will form a link between them. The association will call for explanation and might prove to be of genetic significance. In this connexion Clarke's suggestion would be of great interest. Referring to the occurrence of vanadium in lignite, asphalt, grahamite and manjak, he states: "These ash analyses, taken together with the finding

of vanadium in the ashes of wood and peat, suggest that plants have played some part in the concentration of vanadium." The possible bearing of this suggestion on the vexed question of the origin of petroleum should lead petroleum chemists to pay particular attention to the occurrence of vanadium in various crudes and to publish the results of their analyses.

Mr. Guthrie wrote in reply :—

With reference to Dr. Dunstan's remarks he thought his suggestion that the Institution should take an underground storage for preserving large samples of oil an admirable one. With regard to the confusion between the term benzine and benzene the author preferred to use the term " petroleum spirit " for the former, which he has endeavoured to introduce in Egypt, as showing more clearly its origin and although gasoline is the common term used in America, he thought it should only be applied to designate the spirit obtained from natural gas. The author had not noticed any viscosity hysteresis effects in these Hurghada residues. It would have defeated the author's immediate object to have cracked at the higher pressures and temperatures mentioned by Dr. Dunstan, that objective being firstly to obtain from the unsatisfactory residue a thin Diesel oil—in great demand by the irrigation and public utility services in Egypt—and secondly, to obtain a good pitch for road-making. With these ends in view the cracking had to be moderated. Excellent results have, however, been obtained by the author in the production of benzine and kerosene from the residue by cracking at the higher temperatures and pressures mentioned by Dr. Dunstan.

With regard to Mr. A. Beeby-Thompson's remarks it was really more intermediate products that the author wanted, with pitch as a heavy residue. With Mr. Thompson's remarks the author is in entire agreement, only, there is still lacking that close co-operation between the geologist and the chemist without which, at least in tracing the origin of oil and connate subjects, the work of neither will be complete and much good work on both sides will continue to be wasted.

In reply to Mr. Lawson Lomax, the sulphur content mentioned was in the finished benzine. The author cannot agree with Mr. Lomax, that although the sulphur content will certainly increase in the heavier fractions, any formula can be used to tell even approximately the percentage of sulphur which will be found in the residue from the distillation of a crude oil, different oils varying to such an extent in this respect. As a matter of fact, the discrepancy in this case is more apparent than real, and although it has sometimes

perplexed the author, the explanation is, no doubt, a simple one, because, no matter how carefully this oil is distilled, much decomposition, with eliberation of sulphuretted hydrogen, takes place, especially at the higher temperatures after the kerosene has been taken off. As it happens, occasional samples of pitch residue from Hurghada crude have been found to contain 3.5 per cent. of sulphur. With regard to Mr. Lomax's query as to the amount of pitch which the Egyptian market could absorb, this is a steadily increasing quantity, and as pointed out in the paper it is highly probable that, if a cheap indigenous pitch could be supplied in sufficient quantity, the making of good main roads would be distinctly encouraged with the consequent use of large quantities of this product. The author did not suggest, however, that the whole of the Hurghada production should be distilled for pitch. By reference to page 220 it will be observed that in order to obtain a first-class fuel oil—which was one of the main objectives—from the ordinary thick viscous residue, only 25 per cent. of the latter need be distilled for this purpose, so that roughly speaking, only about 25 per cent. of the possible pitch would ever be manufactured. Without going into the main question as to when it pays to extract paraffin wax from a crude oil, the question has no interest for Egypt, at any rate at the present time. The author agreed with Mr. Lomax that it is always difficult to get complete solution when mixing heavy residues with lighter oils, but although he has observed a separation of bitumen in some of the mixtures mentioned in the paper on standing, this does not take place to any appreciable or harmful extent.

With reference to Mr. Wilson's remarks the author agreed that, for the manufacture of lubricating oils, vacuum was the best, indeed the only, form of distillation permissible. With paraffin wax it was different, however, and he knew that in the case of the oil under review, a vacuum distillation defeated its object, for after such a distillation the paraffin distillate could not be filtered. This oil undoubtedly required to be distilled at a high temperature, inducing a certain amount of cracking, in order to convert the paraffin into the crystalline condition in which it could be filtered. The author is inclined to agree with Mr. Wilson that the determining factor in rendering the paraffin amorphous, and therefore difficult to filter, in a mixed base oil, was its intimate admixture with asphaltic and resinous bodies

In reply to Sir Frederick Black; the method used to determine the flowing point was, he believed, the ordinary one of freezing the oil contained in a 1-inch diameter test-tube, a thermometer being immersed in the oil. The tube was then tilted at an angle of 45°, and the temperature noted when the oil resumed the horizontal

position. The point raised by Sir Frederick anent the relation existing between the flowing point and the asphalt content and the lack of relation to the Viscosity (Redwood) was an important one. As a matter of fact the author has no faith in Viscosity determinations (either in Redwood's No. 1 or 2 instruments) as a guide to how heavy asphaltic or mixed base fuel oils will behave in practice.

With regard to Prof. Brame's remarks *re* asphalt in Diesel fuel oils, the author would like to explain that he had always tried to hold the balance between the oil merchant and the Diesel engine manufacturer and user. On the one hand, the merchant often marketed a Diesel fuel oil which was quite unsuitable for this class of work, because it contained too high a percentage of asphalt in an insoluble form, which was not readily combustible. On the other hand, the Diesel maker and user was inclined to demand that only a distillate free from asphalt should be supplied. This demand the author considered absolutely unpractical, and although he has time and again taken the side of the maker and consumer when he has, as the result of investigation, found that break-downs have been due to too high a percentage of asphalt, he has observed that most of the successful Diesel fuel oils in use to-day contain considerable percentages of asphalt, so that manufacturers and users have become reconciled to its presence and have adjusted their engines accordingly. It would therefore be a mistake in the opinion of the author, to spoil them by leading them to expect an oil even approximately free from asphalt.

The author takes this opportunity of thanking Prof. Brame for his kindness in reading the paper on his behalf.

With reference to Mr. Kewley's written communication, the author has found in a sample of finished Hurghada benzine an aromatic content of 12.1 per cent., which approximated to his (Mr. Kewley's) figure. It should be noted, however, that the author was not discussing finished products, but distillates from a distillation conducted under *vacuo* in an endeavour to find out the nature of the chemical components in the original oil, and not as they have been changed when converted into finished products.

When this work has been completed it is hoped to put the results before the Institution in the form of a written communication.

Mr. N. A. Anfilogoff subsequently wrote :—

The paper shows how important it is to go through the drudgery of preliminary analysis and experimental work in order to become really acquainted with the products that are obtainable from any given crude and the best process to be employed for the obtaining of economic results.

Unlike most practical refiners Mr. Guthrie tabulates the results and the arguments, for and against, with a frankness which is commendable and of real value to his colleagues who are engaged in the refining of petroleum.

One of the points brought out in the paper shows how variously "cracking" affects various grades of petroleum. In the case under review moderate "cracking" resulted in the entire disappearance of the high melting-point waxes present in that crude, and yet it is on the moderate "cracking" that the refiner usually depends for the conversion of paraffin in an amorphous condition into a paraffin of crystalline form.

One point to which he desired to draw the attention of the author, as well as of the Standardisation Committee, was the penetrometer test for pitch.

The penetrometer uses a needle loaded with 100 grams and the tests consist of the depth that needle will penetrate with that weight at a certain temperature during say five seconds. At best it is only useful for comparative purposes and does not give any tests for hardness.

In his laboratory at Thames Haven the Vicat needle has been substituted for the indefinitely pointed needle supplied with the penetrometer, and he suggested that the Vicat needle (the same as is used for cement-hardening testing) having a definite area (one square millimetre) must give more intelligent results and some *calculable* measure for the hardness of pitch.

It will be readily understood that with a Vicat needle the superimposed weight could be increased, and instead of having such a limited period of time as five seconds for the test the penetration could be measured over a longer period of time and so more readily show the resistance of the pitch to penetration.

MR. GUTHRIE replied thanking Mr. Anfilogoff for his remarks, and also for his suggestion that the Vicat needle will give more intelligible results in estimating the hardness of a pitch. He (the author) intends to have the Vicat needle tried in his laboratory at the earliest opportunity.

Re PROFESSOR J. S. S. BRAME'S Presidential Address on

"Fire Hazards and Fire Extinction."

The following has been communicated by **Mr. J. T. Hayward**:—

In 1912, a certain bailing well in a Rumanian field was burnt down three times in as many weeks. An examination showed that the brakes and electric motor were in good order, and the workmen were, at any rate on the latter two occasions, too intimidated to smoke. The men, upon cross-examination, insisted that "the fire came out of the hole," which was at the time believed to be impossible. The well was being bailed by means of a Canadian drilling rig, and the weather was at the time very dry. The writer came to the conclusion that the fire was started by electrostatic sparks produced in the following way.

When the bailer is just entering or leaving the casing, the manipulant retards the spool by tightening the brake and allows the belt to slip under more or less tension. This is the condition favourable to the greatest excitation, and the spool, resting on a wooden frame, might become highly charged. If it should happen that the bailer, partly or completely in the casing, should for a second or two not be in contact with it, a condenser would be formed—a condenser in its classical form, the Leyden jar, the casing forming the outer coating, the bailer the inner, and the intervening air or gas the di-electric. This Leyden jar could be charged by the bailing line, which passes directly from the spool, over the crown-block to the bailer, and the charge would build up until the bailer swung near to the casing, when spark-over would occur. The whole arrangement is very similar to the old-fashioned glass cylinder friction machine, the spool and belt representing the cylinder and pad, the bailer and casing the jar, and the cable the chain. A more dangerous arrangement could hardly be imagined.

In order, if necessary, to be able to demonstrate the correctness of the above theories, the following apparatus was made, and experiments tried. A gold-leaf electroscope was made. Various steam jets on the field, due to leaks, etc., caused the leaves to diverge from a distance of four or five metres. The machinery and sheds of several bailing wells and Canadian rigs were examined in this way. The conditions were found to be very variable. At one time a roof would show strong charge, and at another time none. A Canadian belt from band-wheel to spool was found at times to show a very strong charge. A belt "running light" from an electric motor to a layshaft, was noticed to show strong charges. A model of a shed roof was made as follows: a piece of sheet iron,

as used in roof construction, 200 m.m. by 300 m.m., was nailed upon a board slightly larger, the nails passing right through. The whole was then mounted upon a glass rod. This was placed 500 m.m. from a driving belt (a belt from a motor to a bailing machine). An earthed metal body was then moved towards the back. Spark-over took place with a gap of 50 m.m., the spark stream being very brilliant. A small Leyden jar was charged, giving an unpleasant shock, and in another experiment the charge was caused to pass through the gas given off by a small receptacle containing benzine, which was at once ignited.

The result of these and other similar experiments, together with some suggestions for precautions to be taken for avoiding the danger were published by the writer in 1915 or 1916.

Aviation Spirit—Past, Present, and Future.

By A. E. Dunstan, D.Sc., F.I.C., F.C.S., and F. B. Thole, D.Sc., F.I.C., F.C.S.

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The volatile fuel of the high speed internal combustion engine has in the past consisted almost exclusively of the lighter distillates from crude petroleum. In earlier days, when the value of kerosene far exceeded that of gasoline, the latter being practically a waste by-product, motor fuel had a final boiling-point averaging 120° C. With increasing demand for motor spirit the upper limit of boiling-point of this fraction steadily rose till to-day it frequently reaches 220° C. This increase in average boiling-point of the fuel has both advantages and disadvantages. It means that a much larger proportion of crude petroleum can be utilised as motor fuel, while the higher specific gravity of modern gasoline means that a larger quantity of energy, measured in British Thermal Units, is contained in a gallon of the spirit than was formerly the case. On the other hand, the higher proportion of less volatile hydrocarbons renders starting less easy and effective vaporisation more difficult, with the consequent troubles of uneven carburation and possibly even dilution of the lubricating oil. These last mentioned drawbacks are more or less overcome in modern engines by heating the inlet manifold, a somewhat unsatisfactory compromise, since for fullest efficiency the explosive mixture should be as cold as is permissible.

A more serious difficulty lies in the fact that the heavier "paraffinoid" hydrocarbons in gasoline when vaporised and mixed

with air give a mixture somewhat susceptible to "detonation," *i.e.*, propagation of the explosion with a velocity far greater than that of the normal explosive wave. This excessively rapid explosion, instead of being converted into effective propulsive power, gives a hammer-like blow to the cylinder and piston resulting in the well-known "pinking." This tendency to detonation increases rapidly as the compression ratio is raised and as higher efficiency results from increased compression ratio the trend of modern aircraft engineering is to produce motors with so high a compression that normal straight run petroleum distillates consisting of paraffin hydrocarbons can hardly be used.

The limitation of final boiling point to 150° C. laid down in the Air Ministry specification for Motor Spirit has the twofold object of obtaining a readily vaporisable fuel and of excluding these higher boiling paraffin hydrocarbons which are prone to detonation in aircraft engines. It has the serious result, however, of limiting the amount of gasoline available both for aircraft and for transport purposes, for an increase in the demand for the aviation "cream" involves a disproportionately greater limitation in the volume of transport "milk" available, since the latter cannot be skimmed beyond a certain degree. Modern fuel research is directed to the double problem of increasing the supplies of gasoline and of discovering ingredients—which may or may not be fuels—which will overcome the detonation difficulty and so enable heavier grades of petroleum to be used.

Much of our knowledge regarding the effects of compression ratio on the efficiency of engines and on the suitability of the various fuels employed is due to Ricardo. He proved by using a variable compression engine that while paraffinoid hydrocarbons, and to a somewhat less degree naphthenic hydrocarbons, are rather prone to detonation, benzole, toluol, and xylol will withstand very high compression ratios without detonation occurring. The presence of these aromatic hydrocarbons is therefore of considerable value in a motor spirit, and especially in an aviation spirit. In order to obtain a spirit which can be used without marked tendency to detonation in high compression engines the Air Ministry specifications, besides excluding hydrocarbons boiling above 150° C., insist on the presence of a certain minimum proportion of aromatic hydrocarbons. Some spirits from Borneo, Sumatra, Burmah, and Persia already contain these aromatic hydrocarbons, but most other spirits have to be blended with the benzol and toluol derived from coal to fulfil the requirements.

The question at once arises as to the possibility of procuring sufficient material to fulfil these requirements in the event of war or of widely increased development of aircraft. Obviously in the former case the demands on aromatic hydrocarbons for

explosives supply will be enormous and will create a serious strain not only on the coal-tar, coal-gas and coke-oven industries, but also on those petroleums which contain notable amounts of benzene and toluene. Benzol is, however, by no means the only substance which possesses "anti-detonating" qualities. A considerable range of alternative fuels capable of incorporation with gasoline are available to serve the double function of increasing the volume of spirit at our disposal and improving its qualities for aircraft use.

Alternative and Supplementary Motor Fuels—Tetralin, Dekalin and Tetralin-Extra.

Coal-tar contains a large amount of naphthalene, the potential production in this country being of the order of 50,000 tons per year, although the present demand is small. The quantity could be greatly increased in all coal-producing countries. Although an admirable fuel, it is a solid melting at 80° C., and not readily soluble in petrol, so that its utilisation as such has obvious disadvantages.

By union with hydrogen the solid naphthalene is converted into a mobile liquid, and two distinct compounds are obtained according to whether one or both of the benzene rings are hydrogenated. These are tetrahydronaphthalene or tetralin, $C_{10}H_{12}$ (b.p. 206° C.), and decahydronaphthalene or dekalin, $C_{10}H_{18}$ (b.p. 175° C.). As in the case of the hydrogenation products of benzene, there is a complete change in the characteristic odour on hydrogenation and alteration in the physical properties, there being a steady lowering of the boiling point and the specific gravity as the substance is hydrogenated. The hydrogenation seems to take place in two stages only, either one or both of the benzene rings being saturated, no intermediate partially-saturated rings being formed. There is, however, an intermediate product between tetralin and dekalin, known as "tetralin extra," a mixture of about 20 per cent. tetralin and 80 per cent. dekalin. Dekalin is a completely saturated body and therefore practically chemically inert, but tetralin is partially unsaturated and therefore behaves to some extent as an olefinic hydrocarbon.

Tetralin, unlike benzene and hexahydrobenzene, decolorises an alkaline solution of potassium permanganate. Tetralin is also capable of autoxidation in the same way as unsaturated hydrocarbons, such as turpentine. If exposed to the air for a long time or evaporated over a water bath at a low temperature it resinifies.

Tetralin has been suggested as a motor fuel when mixed with benzol, alcohol, or petrol. Its high boiling-point would preclude its use undiluted.

Cyclo-hexene.

When phenol is reduced by hydrogen in the presence of nickel the alcohol cyclohexanol is produced. Catalytic dehydration of this yields cyclo-hexene, boiling at 82-84° C. In a similar way the homologues of phenol yield tetrahydro-aromatic hydrocarbons.

Alcohol Fuel derived from Coke-Oven Gases.

It is very well known that coke-oven gas, coal-gas, and the gases from cracking heavy oil and from general distillation plant contain unsaturated hydrocarbons, particularly ethylene and propylene. These reactive bodies are soluble in sulphuric acid, yielding alkyl hydrogen sulphates which after hydrolysis give alcohols.

The alkyl sulphates are hydrolysed by means of superheated steam and the alcohol distilled off. The residual diluted acid is re-concentrated. The experiments at Skinningrove, where coke-oven gas was purified from hydrogen sulphide, carbon bisulphide, and carbon dioxide, and then passed through 95 per cent. sulphuric acid at 60° C-80° C., showed that 70-80 per cent. of the ethylene was absorbed quite rapidly. The concentration of the acid was reduced to 77 per cent. during the absorption and after hydrolysis to 74 per cent.

In the case of gases from cracking processes the problem is complicated because in addition to ethylene there are present propylenes, butylenes, and also diolefines, such as butadiene, all of which are soluble in and combine with sulphuric acid. Selective treatment of the purified gases with different strengths of acid and at different temperatures will yield the desired alkyl compounds from which the alcohols may be obtained in the usual way. A further line of attack is to convert the olefines into chlorhydrins by the action of aqueous hypochlorous acid. The chlorhydrins are reactive compounds and by regulated treatment with alkalis they yield inner ethers. These ethers are combustible and potential fuels. The first member of the series, ethylene oxide, boils at 12° C. and has specific gravity 0·898. Propylene oxide boils at 35° C. and iso-butylene oxide at 51° C.

The great potentialities in the production of alcohol from the fermentation of sugar waste and from the hydrolysis of various naturally occurring bodies (wood, starch, etc.) has been so widely described and discussed that the matter need not be elaborated here.

Alcohol *per se* will probably not be used as a motor fuel, at any rate in the near future. Its immediate advantage appears to

lie in the fact that it withstands high compressions and is exceedingly reluctant to detonate. It would therefore find its ideal use in a gasoline blend or for subsidiary use in cases where detonation has already set in. A serious difficulty lies in the fact that owing to its inevitable water content commercial alcohol will not readily blend in small proportions with gasoline. Much research is yet needed on this subject.

Various mixtures of alcohol with liquids of high vapour tension have been proposed. The obvious ether is used in Natalite and can very readily be obtained by passing alcohol vapour over heated alumina.

Acetone also is of service in this connexion and is obtained by the destructive distillation of calcium acetate.

Important work on the production of acetone by fermentation has been carried out by Fernbach, who, by means of a special bacillus, has been able to ferment starch into butyl alcohol and acetone. Acetone boils at 56° C. and is therefore sufficiently volatile to ensure easy starting.

A fuel blend containing acetone is described by Ricardo (E. P. 183,577) as containing 60 per cent. alcohol, 20 per cent. acetone, 10 per cent. benzol and 10 per cent. water.

A new field of supplies is opened out by the work of Bergius, who claims to have successfully hydrogenated not only heavy petroleum residues, but also coal, and to have produced considerable amounts of light hydrocarbons therefrom. The operation consists in heating heavy oil or coal to its incipient cracking temperature and then hydrogenating at the moment when the molecules are at the point of scission. The pressure needed for this procedure is relatively high and of the order of 100 atmospheres. Consequently the plant must be constructed to withstand very great stresses and must be isolated when working. The work of Bergius may be of the greatest importance, seeing that every coal field becomes a potential oil field. It has yet to be proved that the light fractions are equivalent to straight-run gasoline in operation, but it is certain that if or when large amounts of spirit are produced by this process the motor industry would be able to utilise it.

Somewhat analogous to the research of Bergius is the investigation of Fischer, who has shown that coal heated with sodium formate or with carbon monoxide and steam yielded very considerable amounts of oil and within the same category comes the production of coal-oil by the various low temperature carbonisation processes which are slowly advancing towards the goal of commercial success.

Although the time is not ripe for the production and utilisation of oil derived from coal, the period approaches when shale products will prove an inevitable adjunct to petroleum—ultimately perhaps to supplant it. The venerable Scottish Oil Industry is still with us

and will remain for all time a monument to the persistence, skill, foresight, and courage of its founders and operators. The present yield of shale-oil is, however, a very small part indeed of that needed to supply the country's demand, and it is to the great deposits of Utah, Colorado, Australia, etc., that industry must look for supplies. Just as we are now living in the petroleum age, so without any doubt will the immediately following generations have their being in the oils derived from coal and shale.

Engineering progress will be fully tested in developing aircraft and road motors for the utilisation of heavier fuels than gasoline; already, in fact, have interesting experiments been carried out in the direction of employing both road and aero-engines of the Diesel type. There is a huge reservoir of intermediate oil yet to be made use of, since for every ton of gasoline the average crude petroleum yields from five to ten tons of kerosene and heavier oils. Much attention is at present directed to cracking these heavy oils in order to convert them partly into gasoline, but it would clearly be more logical to devise engines to suit the fuel available rather than to convert the latter into gasoline at the expense of costly plant and considerable losses in material.

In view of the possible improvements in the functioning of fuels indicated in the present paper great interest attaches to recent experiments in which the cooling system radiator of a car was filled with light spindle oil instead of water. Provided certain obvious difficulties, such as lubrication, could be overcome, it should be possible by this means to raise considerably the working temperature of our engine and thereby vaporise completely before combustion fuels of higher final boiling-point than are permissible at present. The low specific heat of oil would be balanced by the higher temperature so that no increase in the size of the radiator would be necessary.

Detonation and Anti-Knock.

Considerable interest attaches to the value of hydrogen in this connexion, since as the fuel of an airship is consumed the lifting power necessary diminishes and hydrogen becomes available and may have to be blown to waste. Since hydrogen is not prone to detonation, the ingenious and effective scheme has been suggested of supplying the engines of an airship with a mixture of heavy grade petrol or even kerosene with hydrogen in appropriate quantity to balance fuel load against lifting capacity.

In any discussion of motor fuels two aspects must always be borne in mind—the possibility of production of greater supplies of fuel and the possibility of improving the qualities of the fuel available. In the first section of this paper the first aspect has been the more fully dealt with, but at the present time the supply

of motor spirit is at least equal to the demand, and increasing attention is being paid to means whereby this spirit can be rendered more suitable for efficient use in modern engines. As has already been indicated, the principal factor is the tendency of the fuel to detonation.

In considering the phenomena of "detonation," care must be taken not to confuse this with the entirely different phenomenon of "pre-ignition," though each of these are causes of the same result, "pinking."

Pre-ignition of the charge, *i.e.*, explosion before the end of the compression stroke, is generally due to an overheated engine, to too early spark timing, or to incandescent points in the cylinder, any of which will cause a premature explosion, the impact of which on the rising piston will give a "knock." It is nearly impossible to produce "pre-ignition pinking" in a cold engine if the spark is properly adjusted.

"Detonation pinking," on the other hand, can take place in a cold engine with correct timing of the spark, provided the fuel mixture and compression are such that the explosion velocity is extremely high, though conditions which tend to produce pre-ignition are in many cases also favourable to detonation.

Viewed from the standpoint of detonation characteristics, fuels fall into two classes:—

(1) "Straight" fuels (or mixtures of them), such as:—Petrol; Aromatic hydrocarbons; Alcohol.

(2) "Straight" fuels to which have been added very small quantities of certain materials called "anti-knock."

The most important of these anti-knock materials are certain volatile organic compounds of lead, tin, tellurim and selenium, and aromatic amines.

Fuels in the first class were examined by H. R. Ricardo (1921), and Midgley and Boyd (1922) repeated Ricardo's work on fuels of the first class (with results slightly differing from his in some respects) and carried on investigations on fuels of the second class.

Ricardo's Work.

Ricardo used a special single-cylinder engine, the compression ratio of which was infinitely variable between the limits of 3·7 : 1 and 8:1.

He found that various fuels (all of the first class) could be used with the following "highest useful compression ratio":—

Petrol (various brands)	4·55 : 1 to 6·0 : 1
Benzene (98 per cent.)	6·9 : 1
Toluene and Xylene .. .. .. above	7·0 : 1
Alcohol (98 per cent.) .. .. .. above	7·5 : 1
Methylated Spirits	6·5 : 1

In this engine it was impossible to cause alcohol, toluene or xylene to detonate. The above "highest useful compression ratio" for a particular fuel is the ratio above which detonation commences when the mixture and ignition are both adjusted for maximum efficiency. He found that by mixing hexane and an aromatic hydrocarbon the highest useful compression ratio could be determined from a linear curve. He proposed toluene as the standard with which fuels are to be compared. Thus:—

Fuel.	Toluene Value.
Toluene	100%
Benzene	67%
Alcohol	88%

The Work of Midgley and Boyd.

An important improvement adopted in Midgley's experimental engine was the use of an apparatus to measure the amount and intensity of detonation, Ricardo depending on oral observations only.

The engine compression was not infinitely variable, but by means of 3 or 4 detachable cylinder heads he could obtain certain definite compression ratios at which to measure the detonation produced by various fuels (3·5 : 1 to 5·4 : 1).

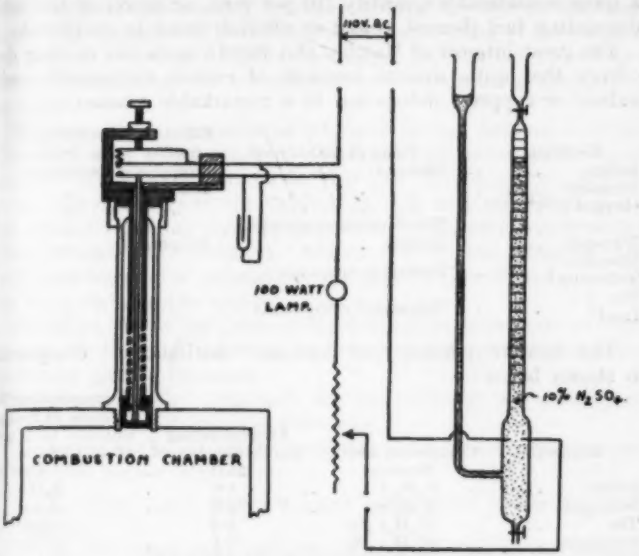
The detonation-measuring apparatus consists of an opening in the head of the combustion chamber which is fitted with a small piston. The bottom of this piston is flush with the inner surface of the cylinder head and the piston is held down by a powerful spring. On the upper side of the piston there rests, merely by gravity, a heavy steel pin.

Above the pin there are a pair of contact points connected in series with a source of current (110 volts. D.C.) and an electrolytic cell.

During normal combustion the piston only moves up and down a minute distance (a few thousandths of an inch), and the pin moves with it. When detonation occurs, the pin is thrown free of the piston and closes the circuit, thus causing gas to be collected in the cell.

Midgley used kerosene as the basic fuel, since this produces considerable detonation with the fairly low compressions available to him. His standard fuels for comparison were made by mixing various proportions of the kerosene with xylidine in the earlier experiments, but later he used benzene standard mixtures.

The mixture of fuel and air used in each case was the one producing maximum detonation. This is also the leanest possible mixture for maximum power. During each set of comparative tests the same spark setting was used.



MIDGLEY'S BOUNCING PIN APPARATUS.

The fuel system of the engine was arranged in duplicate so that alternate one-minute runs could be made with the two fuels to be compared. When determining the detonation characteristics of a particular fuel, the fuel is placed in one tank and in the other are placed in turn those xylidine/kerosene mixtures which respectively give rather more detonation and rather less detonation than the given fuel. By making one-minute runs with each fuel and by noting the volume of gas evolved in each case (which is assumed to measure the amount of detonation), then, by means of a curve, the exact xylidine/kerosene mixture corresponding to the particular fuel can be determined and hence the fuel is standardised.

It would appear doubtful if the bouncing pin method measures the intensity of the detonation as well as the frequency of its occurrence.

Midgley compared blends of many straight fuels, using the xylidine/kerosene standard. He used blends of kerosene with benzene, with other aromatic hydrocarbons and with alcohol.

In the main his results confirmed those of Ricardo, though he considered xylene to be more efficient than toluene as a restrainer of detonation, whereas Ricardo considered it less efficient. Both Midgley and Ricardo show clearly that to produce any real effect

a quite considerable quantity (10 per cent. or more) of the anti-detonating fuel (benzol, toluol or alcohol) must be employed.

The great interest of Midgley and Boyd's work lies in their discovery that quite minute amounts of certain compounds could induce or suppress detonation in a remarkable manner.

Element.	Form in which used.	Effect on detonating quality of a fuel.	
Iodine	Element	Suppresses detonation	
Bromine	"	Induces	"
Oxygen	"	"	"
"	Ethyl nitrite or nitrate	"	"
Nitrogen	Aniline	Suppresses	"
Selenium, Tellurium	Diethyl compounds	"	"
Tin, Lead	Tetraethyl compounds	"	"

The relative efficiency of various "anti-knock" compounds is shown below:—

Element.	Compound used.	Corresponding percentage by vol.	Corresponding No. of mols. of fuel/air mixture to 1 mol. of anti-knock.
—	Benzene	25·0	150
Iodine	C_2H_5I.	1·6	2,150
Nitrogen	Xylidine	2·0	2,600
Tin	$(C_2H_5)_4Sn$	1·2	7,100
Selenium	$(C_2H_5)_2Se$	0·4	11,750
Tellurium	$(C_2H_5)_2Te$	0·1	50,000
Lead	$(C_2H_5)_4Pb$	0·04	215,000

The small amount of these "anti-knocks" necessary to suppress detonation is very striking. If an open bottle of diethyl selenide be held in the air inlet of a violently detonating engine, all detonation will at once cease. If a bottle of ethyl nitrite be held in the air inlet of a smoothly running engine violent detonation will at once occur. Very small amounts of these substances also cause acetylene mixtures to burn quietly when used in an explosion tube. It has not proved possible to predict from the knowledge at present available the general nature of effective "anti-knocks." Thus bivalent lead compounds are inoperative, while nitrogen in nitrites and in amines gives diametrically opposed results.

The mechanism of detonation and of its suppression is at present by no means thoroughly understood, though its effects are, of course, unmistakable. Ricardo considers that combustion at first occurs normally when the mixture is sparked. The flame spreads and compresses before it the yet unburnt portion of the charge. This unburnt portion gets hotter through this compression and when more heat is supplied thus than is dissipated through the cylinder walls, then the self-ignition temperature is in time reached and the gas spontaneously explodes. The explosion wave set up strikes the walls of the chamber and causes the "pinking" noise.

The different detonating qualities of fuels are due to the lower rates of propagation of flame, since the compression of the unburnt gas in front of the wave will be slower and the heat will have longer time to dissipate, so that the self-ignition temperature is not reached so easily.

Midgley's views are similar in substance though differing in detail. He states that a difference of pressure exists between the front and rear of any explosion wave. Up to a certain critical pressure in the rear of the wave, the value of P_1-P_2 is only small, but above this critical value the value of the pressure difference becomes very great (theoretically infinity). Above this critical pressure the explosion becomes a detonating one and the knock is caused by the wave striking the walls.

Therefore, the factor determining detonation is the rate of combustion of the fuel mixture, a greater velocity of combustion producing greater pressures.

The "anti-knock" materials act by reducing the velocity of combustion of the mixture in some way.

The action of the materials mentioned bears considerable analogy to catalytic action because :—

(1) Very small amounts exert remarkable effects on combustion,

(2) The effect does not increase in proportion to the amount present, but a maximum point reached,

(3) The final equilibrium is unchanged,

No information is yet available as to whether the products of combustion of Midgley's compounds have any harmful effect on the lubricating oil or whether it is essential that these compounds must be volatile in order to be effective. The cost of production is also an important, though no doubt a readily soluble problem. It seems highly probable that research on these lines will, in the not distant future, overcome the principal disadvantage attaching to the heavier petroleum distillates and result in the extensive use of extremely efficient high compression engines consuming a "doped" heavy grade gasoline.

The Nature of Lubrication in Engineering Practice.

By T. E. Stanton, C.B.E., F.R.S., D.Sc., M.Inst.C.E., F.R.Al.S.

(*A paper read before, and published by permission of, the International Air Congress, London*, 1923.)

During the last five years considerable modifications have taken place in the views held by engineers of the action between the lubricated surfaces of the machines in which they are interested. Previous to this time it was a common, if not universal, assumption that the conditions of steady lubrication in engineering practice involved the actual separation of the rubbing surfaces by a film of oil in the manner which had been so clearly demonstrated by Beauchamp Tower in his experiments on cylindrical journals for the Institution of Mechanical Engineers in 1888. It was not surprising, therefore, that, when Osborne Reynolds showed that all the phenomena observed by Tower could be predicted from the hydrodynamical theory of the flow of a film of oil between the lubricated surfaces, the existence of such a film should have been deemed essential to all cases of lubrication and that the limitations of the hydrodynamical theory should not have been recognised.

This assumption is the more excusable from the fact that although these limitations were doubtless fully recognised by Reynolds, they were not expressly stated in his work on the subject beyond a somewhat obscure reference in the last paragraph of his paper to the inefficiency of the lubrication of surfaces in relative reciprocating motion. It must be admitted, too, that Reynolds' statement that "whenever hard surfaces slide over each other without abrasion they are separated by a film of foreign matter" is not beyond criticism, in the sense in which the word film was apparently used in his paper. It is now known that hard surfaces can move over each other without abrasion without the existence of a separating film of more than molecular dimensions, but this is a comparatively recent discovery.

The Reynolds theory of lubrication is so well-known that I need hardly point out that the logical consequences of its acceptance are that the value of oils as lubricants depends solely on their viscosity, and that the nature and composition of the rubbing surfaces have nothing to do with the efficiency of the bearing. Curiously enough, the acceptance by engineers of these consequences has not been at all general. Our experience during the last twenty years at the National Physical Laboratory has revealed a considerable demand for wear tests on metals suitable for lubricated bearings and a general disclination of clients to be convinced that when the

lubrication was satisfactory, wear was impossible, and that one lubricant was as good as another so long as its viscosity was up to a given standard.

The existence of this feeling has been well brought out by Dr. Lanchester, who has insisted that, from the days of the millwrights of last century, engineers of wide experience have been fully alive to the fact that animal and vegetable oils were superior as lubricants to mineral oils of the same viscosity in virtue of some characteristic for which there was as yet no definite test.

Up till comparatively recently, it has been common to meet these objections by the statement that the Reynolds theory is not concerned with the manner in which the film is formed, but only with the conditions which exist when it is formed, and that it may well happen that in starting up machines from rest when the bearing surfaces are in contact, certain special characteristics of lubricant and bearing surfaces may be essential not only to prevent excessive wear, but to ensure conditions favourable to the formation of a separating film.

Gradually, however, it has become more and more certain that there can exist between rubbing surfaces a condition of steady lubrication whose characteristics are totally different from that of the Reynolds type.

In laying the foundation of the theory of this type of lubrication, it must be confessed that engineers have taken little part, and the modern conception of its action is, in the main, due to the advances which have been made in the domain of physical chemistry with regard to the molecular phenomena occurring at the surfaces of solids and the manner in which films of foreign matter are condensed on these surfaces by the process known as adsorption.

It is now recognised that solid surfaces having an adsorbed layer of lubricant of only one molecule in thickness can slide over each other with comparatively small frictional resistance.

Further, it is known that adsorption is dependent upon the chemical constitution of the lubricant and that the greater the work done in the process of adsorption, the less the frictional resistance of the surface to sliding.

Acids, alcohols and esters are more strongly adsorbed by water than are paraffins, and it is found that the former are better lubricants than the latter.

There are, therefore, two essentially different kinds of lubrication. In the one, the surfaces are separated by a film of lubricant many hundreds of molecules in thickness, so that the resistance to relative motion of the surfaces is due to the lubricant in mass and the effect of the reactions at the two interfaces of lubricant and solid surfaces is negligible. In the other, the molecular reactions at the common boundary constitute the whole of the resistance, which is therefore

a function of the nature of the surfaces and the chemical constitution of the lubricant.

In the former case, the frictional resistance is determined by the viscosity of the lubricant and by the relative speed, configuration and attitude of the rubbing surfaces.

In the latter case it has been found by Mr. W. B. Hardy, to whose researches on this kind of lubrication much of the existing knowledge of the subject is due, that the coefficient of friction under these conditions may be written $\mu=\mu_0-aM$, where M is the molecular weight of the lubricant and a a constant depending on its chemical constitution, μ_0 being a function of the friction of the surfaces when chemically clean.

Mr. Hardy has also shown that in this kind of lubrication which he has termed "boundary lubrication" the relation known as Amonton's Law, or the Law of Solid Friction, is strictly followed, *i.e.*, the friction for a given normal pressure between the surfaces is independent of relative speed and area of contact.

It should be remarked that owing to the extreme difficulty of preventing the adsorption of a film of foreign matter by any clean metal surface, the scientific study of boundary lubrication has hitherto been confined almost entirely to chemical laboratories, in which alone such contamination can be dealt with.

The importance, however, of the investigation of the extent to which boundary lubrication obtains and the way in which its characteristics may be modified under engineering conditions will be obvious from considerations of the enormous saving in cost of lubrication which might follow increased knowledge in this respect, and several attempts have recently been made at the National Physical Laboratory to set up conditions under which boundary lubrication could be conveniently studied on an engineering scale. The first series of experiments of this kind were made on the well-known machine designed by Dr. F. W. Lanchester for testing the efficiency of worm gears. That the lubrication between the surfaces of the worm and worm wheel in these gears was essentially boundary lubrication appeared to be certain from the results of the efficiency tests, which indicated a marked superiority of the animal and vegetable oils over the mineral oils as regards the temperature at which the gear could be run without a serious increase in the friction.

The conditions of the test, however, were not favourable to the detailed study of the action between the surfaces, and in 1922 an attempt was made to imitate the conditions of pressure and arc of contact of surface in these gears in a cylindrical journal and bearing in continuous relative movement. The results of these tests, however, showed clearly that, although pressures of 3·5 tons per square inch between the surfaces, and arcs of contact of 14 degrees

were obtained, the lubrication was undoubtedly that of the Reynolds type, since it was possible to measure the pressure of the oil film and its distribution by means of a Bourdon gauge connected to a hole in the bearing. The pressure distribution in the case of castor oil, with an arc of contact of 15 degrees, is shown in Fig. 4, and the agreement with the theoretical pressure distribution calculated from the Reynolds theory is seen to be close. In this test the least thickness of the oil film was found to be 0·000046 inch, which corresponds to a film of, roughly, 5,000 molecules thick. This failure to secure the conditions of boundary lubrication is not very remarkable since the relative motion of the surfaces in the two cases of worm gear and continuously rotating journal in all other respects than those mentioned above was widely different, and it appeared evident that the existence of boundary lubrication depended on factors other than those of pressure and area of contact.

After some consideration, an attempt was made to imitate the conditions existing in worm gears somewhat more closely by the adoption of a method whereby, while preserving fairly high intensities of pressure and small arcs of contact, the relative motion of the surfaces, instead of having a steady value, was made oscillatory in character and had a mean value of zero. This condition was suggested by the results of Sommerfeld's analysis of the hydrodynamical problem of the maintenance of a film of lubricant between the surfaces of a journal and a half bearing, which indicated clearly that contact of the surfaces would take place, *i.e.*, the film would break down, when the value of the relative velocity fell to zero.

This condition was effected by the use of a pair of cylindrical lubricated surfaces in the form of a rocking shaft and its bearing, the oscillatory motion being produced by the attachment to the shaft of a heavy pendulum swinging under gravity. From observations on the rate of damping of this system, it was thought that the magnitude and characteristics of the frictional forces at the lubricated surfaces could be determined provided that a steady supply of lubricant could be delivered to the sliding surfaces.

Description of the Apparatus.

The arrangement of the apparatus is shown in Fig. 1. The experimental bearing B, which is 3 in. long by 1·7 in. in diameter, is contained in a cast-iron housing suspended from a bracket bolted to the cross girder supporting the roof of the workshop by means of a pin-point which will allow freedom of adjustment in a direction at right angles to the plane of the swing. By this means the pressure between the surfaces will be symmetrical on either side of the plane of oscillation.

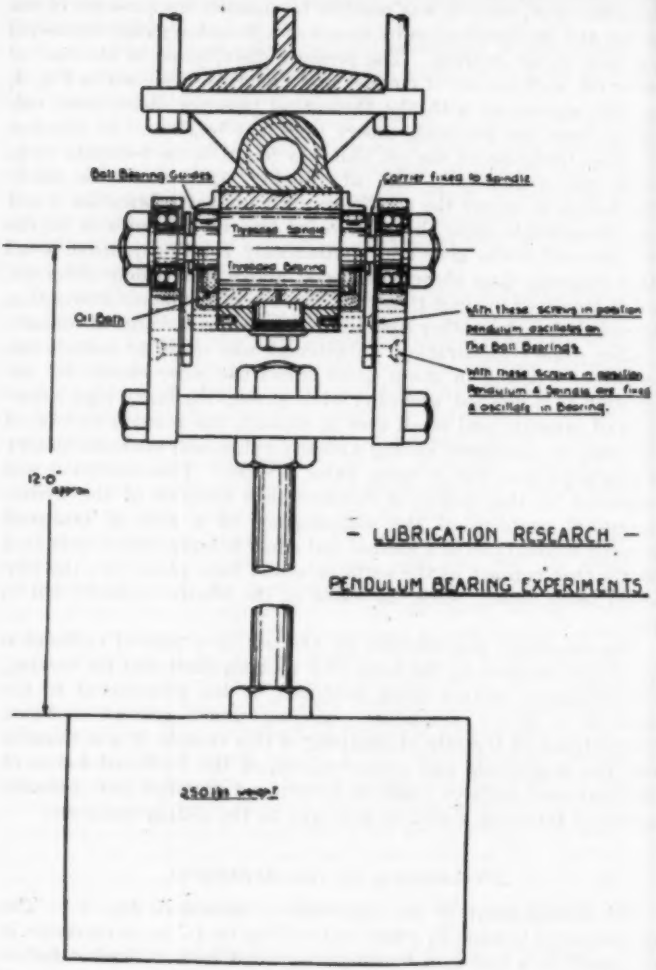
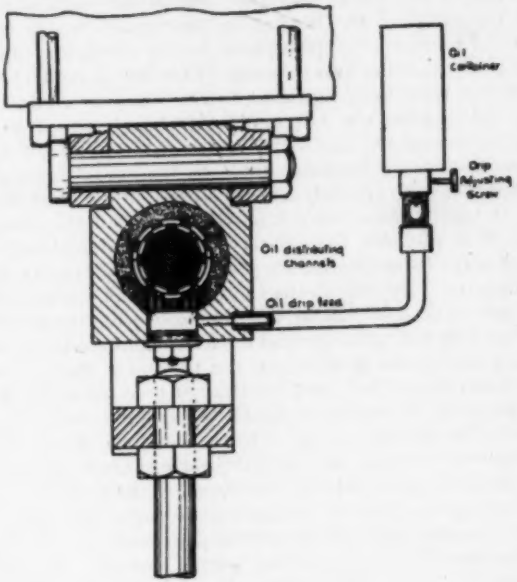

Ball Bearing Guides
Carrier fixed to Spindle
Threaded Spindle
Threaded Bearing
Oil Bath
With these screws in position pendulum oscillates on the Ball Bearings
With these screws in position Pendulum & Spindle are fixed & oscillate in Bearing.
12·0" approx
- LUBRICATION RESEARCH -
PENDULUM BEARING EXPERIMENTS
250 lbs weight

FIG. 1.



JOURNAL WITH SCREW THREAD

An exactly similar thread, but of opposite hand is cut in Bearing. The bearing surface being small squares where the threads cross. Screw thread - 3-38" pitch, square thread, ¼ wide, ¼ deep, 8 starts. A sensing thread ½ wide, ½ deep was cut in the centre of the first three

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FIG. 1.

The total arc of contact of the journal and bearing is restricted to an arc of 45 degrees on either side of the vertical by cutting away the metal of the bearing in the region outside this arc as shown. In order to approximate to the condition obtaining in worm gears that any two elements of surface in contact shall each be covered with fresh lubricant before the next contact, a series of special grooves was cut on the 90-degree arc of the bearing which supported the load. By allowing the lubricant free access to those grooves, a copious supply to the actual bearing surfaces was ensured. A precisely similar series of grooves intersecting these at right angles was cut on the surface of the journal. To obtain this condition the spirals were made right-handed for the bearing and left-handed for the journal, and had a pitch of π times the diameter. By this means the total area of contact of the surfaces was reduced to 0·25 sq. in. In considering the attachment of the pendulum rod to the journal it was thought advisable to provide means whereby the damping of the pendulum due to air friction alone could be studied, and for this purpose a locking device has been adopted, by means of which the rocking shaft can be fixed either to the pendulum rod or to the bearing. In the latter case the pendulum can oscillate on ball bearings fitted to the extension of the shaft on either side of the journal, as shown in Fig. 1. These ball bearings are housed on flitch plates on either side, and lugs fixed to the rocking shaft are provided so that they can be coupled to either the flitch plates or the bearing casting. The lubricant is supplied by a sight feed lubricator to a chamber in the base of the bearing casting, from which the oil is conveyed by the passages shown to the various spiral grooves cut in the bearing. In order to maintain a copious supply of oil to the surfaces, end covers are also fitted to the bearing casting in the manner shown in Fig. 1. By this means oil bath conditions are obtained over the 90-degree arc of contact of journal and bearing.

The Motion of the Pendulum.

From the above description it will be seen that the free oscillations of the pendulum about its mean position will be subjected to damping forces, due to the friction of the shaft in the bearing and the resistance of the air to the motion of the pendulum.

Under these conditions and provided that the amplitude of the oscillations is small, the motion of the pendulum is given by

$$I\ddot{\delta}+W\,L\delta+M_2\pm M_1=0$$

where M_1 is the moment of the friction about the axis, its sign depending upon the direction of the motion,

M_2 is the moment of the air resistance about the axis,
I is the moment of inertia of the pendulum about the axis,
L is the distance of the C.G. of the pendulum from the axis,
W is the weight of the pendulum.

The solution of this equation is complicated by lack of knowledge of the amount of air resistance of the pendulum and its law of variation with speed, but in the case of the present experiments it has been found comparatively easy to use pendulums of such a weight that the actual value of the moment of the air resistance of the pendulum is negligible compared with the value of the moment of the bearing friction. Under these conditions the motion of the pendulum is given by

$$I\ddot{\delta}+W\,L\delta+M_1=0 \qquad . \quad . \quad . \quad (2)$$

If we assume that the friction between the lubricated surfaces follows the laws of boundary lubrication investigated by Mr. W. B. Hardy, *i.e.*, its value is independent of the relative speed of the surfaces, then calling its value F the solution of (2) is

$$\delta=+Fr/WL+A\cos\sqrt{(WL/I)}\,t$$

where r is the radius of the bearing and A is a constant depending on the initial conditions. Assuming that the motion begins when the pendulum is inclined at an angle a to the left of the vertical, then

$$A=-a\pm Fr/WL$$

and the maximum amplitude of the motion to the right at the end of the first half swing is

$$a-2Fr/WL$$

The successive amplitudes of the motion to the right will be

$$a-6Fr/WL$$
$$a-10Fr/WL$$
$$a-14Fr/WL, \text{ etc.};$$

i.e., the damping of the oscillation will proceed at a uniform rate of $4Fr/WL$ radians per complete oscillation. Further, since the time of oscillation of the pendulum is independent of the amplitude of the swings and the friction, it follows that if the successive amplitudes of vibration of the pendulum be plotted on a time base the criterion of the existence of boundary lubrication will be the possibility of drawing a straight line through the extremities of the successive ordinates representing the amplitudes.

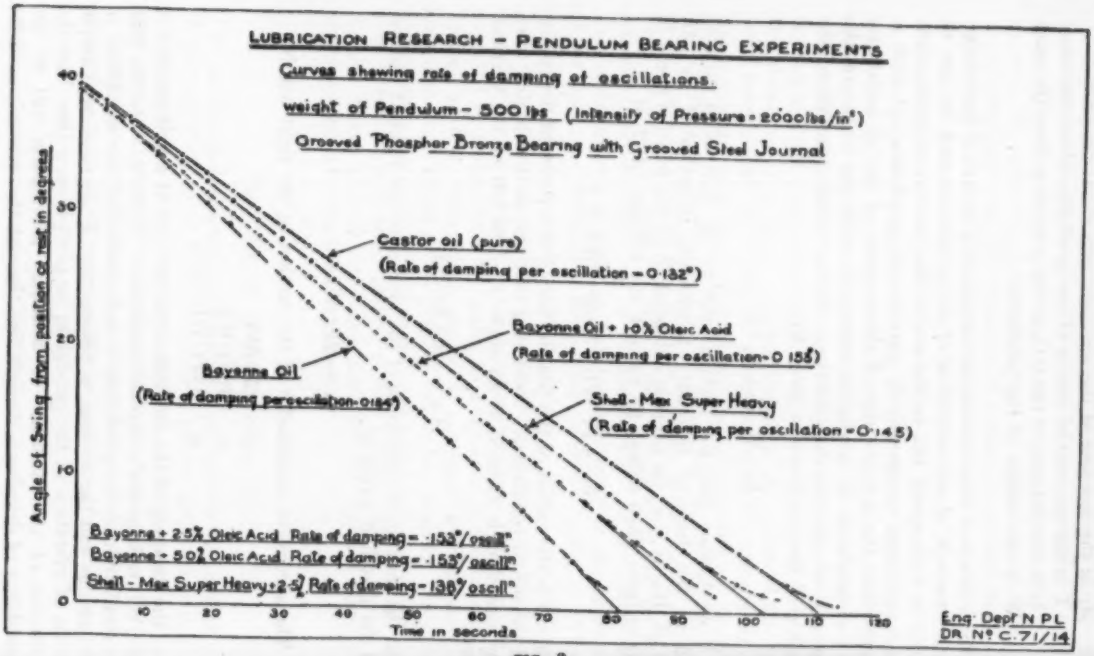
LUBRICATION RESEARCH – PENDULUM BEARING EXPERIMENTS
Curves shewing rate of damping of oscillations.
weight of Pendulum – 500 lbs (Intensity of Pressure = 2000 lbs/in²)
Grooved Phosphor Bronze Bearing with Grooved Steel Journal
Castor oil (pure)
(Rate of damping per oscillation = 0·132°)
Bayonne Oil + 10% Oleic Acid
(Rate of damping per oscillation = 0·158°)
Bayonne Oil
(Rate of damping per oscillation = 0·184°)
Shell - Mex Super Heavy
(Rate of damping per oscillation = 0·145)
Bayonne + 2·5% Oleic Acid Rate of damping = ·153°/oscill°
Bayonne + 5·0% Oleic Acid Rate of damping = ·153°/oscill°
Shell - Mex Super Heavy + 2·5% Rate of damping = ·138°/oscill°
Angle of Swing from position of rest in degrees
Time in seconds
0
10
20
30
40
50
60
70
80
90
100
110
120
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FIG. 2.

— LUBRICATION RESEARCH - PENDULUM BEARING EXPERIMENTS. —

Curves shewing rate of damping of oscillations.

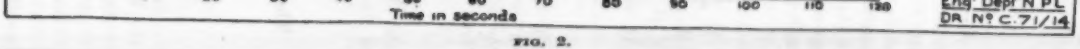


FIG. 2.

— LUBRICATION RESEARCH - PENDULUM BEARING EXPERIMENTS. —

Curves shewing rate of damping of oscillations.

Weight of Pendulum = 250 lbs. (Intensity of Pressure = 1000 lbs/in²)

Grooved Phosphor Bronze Bearing with Grooved Steel Journal

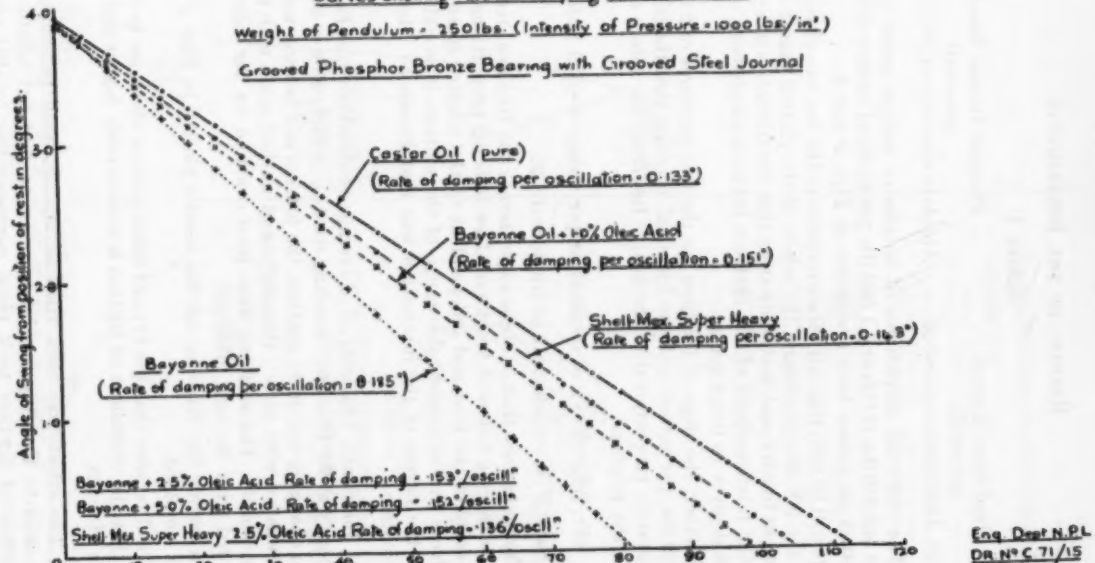


FIG. 3.

Results of the Experiments.

Series I.

Hard Steel Journal (grooved). Phosper Bronze Bearing (grooved).

(*a*) Lubricant—castor oil. Absolute viscosity at 20° C.=7·5.

The observed amplitudes of successive swings under loads of 500 and 250 lbs. (2,000 and 1,000 lbs. per sq. in. of surface of bearing) plotted on a time base are shown in Figs. 2 and 3.

It will be seen that with the exception of the last two observations on the 500 lbs. pendulum, the whole of the plotted points lie on a straight line for each test, indicating that the friction is independent of the relative speed of the surfaces between amplitudes of swing of 8 degrees to 0·5 degrees.

Further, the slope of the lines for the two pressures of 2,000 and 1,000 lbs. per square inch are identical, showing that the friction is accurately proportional to the load. Inserting the values of r and L in the relation

$$4Fr/WL = \text{decay of oscillations per swing} = 0{\cdot}0023 \text{ radians},$$

we have F/W=coefficient of friction=0·092.

From the fact that in these experiments the frictional resistance of the bearing followed Amonton's Law in being proportional to the intensity of the load and independent of the relative speed of the surfaces over a considerable range of the motion, it would appear that the nature of the lubrication was that known as "boundary lubrication."

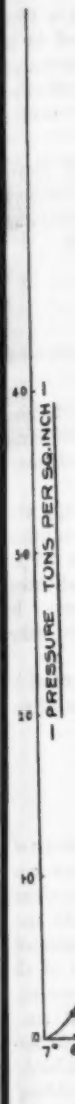
(*b*) Lubricant, a mineral oil of average quality known as Bayonne. Viscosity at 20° C.=1·6. Loading conditions and surfaces as in (*a*).

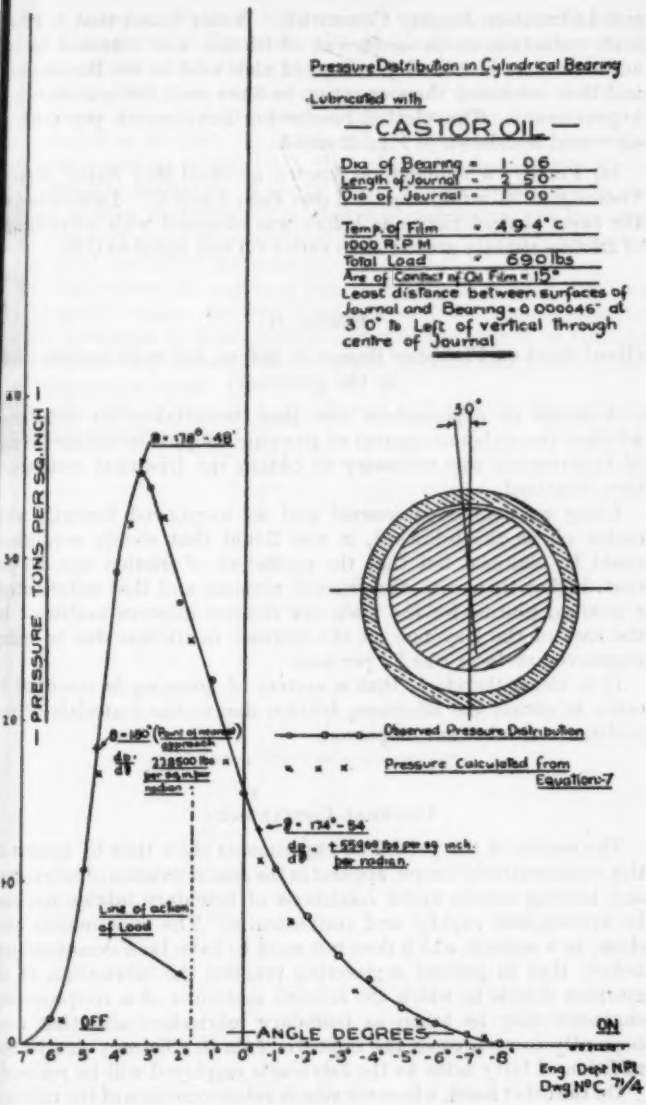
In changing one oil to another, the journal and bearing were first well washed with petrol, then dried and washed again with methylated spirit. The surfaces were then dried in an air blast and covered with the new lubricant.

On testing the Bayonne oil, the results plotted in Figs. 2 and 3 were obtained.

It will be seen that the type of lubrication is the same as before, but that the coefficient of friction is considerably higher and has a value of 0·128.

(*c*) The effect was then tried of adding small percentages of oleic acid to the Bayonne oil in order to find out whether any reduction of friction took place corresponding to that obtained in the worm gear tests previously carried out for the Lubricants




Pressure Distribution in Cylindrical Bearing
Lubricated with
— CASTOR OIL —
Dia of Bearing = 1·06
Length of Journal = 2·50
Dia of Journal = 1·00
Temp of Film = 49·4°c
1000 R.P.M
Total Load = 690 lbs
Arc of Contact of Oil Film = 15°
Least distance between surfaces of Journal and Bearing = 0·000046" at 3·0° lb Left of vertical through centre of Journal
PRESSURE TONS PER SQ.INCH
θ = 178°-48'
θ = 180° (Point of nearest approach)
dp/dθ 228500 lbs per sq inch per radian
θ = 174°-54'
dp/dθ = 555900 lbs per sq inch per radian.
Line of action of Load
OFF
ON
ANGLE DEGREES
7° 6° 5° 4° 3° 2° 1° 0° -1° -2° -3° -4° -5° -6° -7° -8°
30°
Observed Pressure Distribution
Pressure Calculated from Equations-7
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Dwg No C 7/4

FIG. 4.

and Lubrication Inquiry Committee. It was found that a 17 per cent. reduction in the coefficient of friction was obtained by the addition of as little as 1 per cent. of oleic acid to the Bayonne oil, and that increasing the amount up to 5 per cent. did not effect any improvement. The plotted results for Bayonne+1 per cent. of oleic acid are shown in Figs. 2 and 3.

(*d*) Finally, a cylinder oil known as Shell-Mex Super Heavy, viscosity at 20°=9·7, was tried (see Figs. 2 and 3). Lubrication of the same characteristics as before was obtained with a coefficient of friction slightly greater than castor oil and equal to 0·10.

Series II.

(Hard Steel on Phosphor Bronze as before, but with modifications in the grooving.)

A series of experiments was then undertaken to determine whether the elaborate system of grooving adopted in the first series of experiments was necessary to obtain the frictional resistances then obtained.

Using an ungrooved journal and an ungrooved bearing, with castor oil as the lubricant, it was found that steady conditions could be obtained but that the coefficient of friction was 15 per cent. higher than with the grooved surfaces and that substituting a grooved journal for the plain one did not improve matters. In the case of the Bayonne oil the increase in friction due to using ungrooved surfaces was 22 per cent.

It is clear, therefore, that a system of grooving is essential in order to obtain the minimum friction due to the materials of the surfaces and lubricant employed.

General Conclusions.

The results of the pendulum experiments show that by means of this comparatively simple apparatus the characteristics of lubricants and bearing metals under conditions of boundary lubrication can be investigated rapidly and conveniently. The experiments also show, in a manner which does not seem to have been demonstrated before, that in general engineering practice the lubrication of all machine details in which the relative motion is of a reciprocating character may be taken as boundary lubrication and that consequently in such cases the improvements in efficiency due to the addition of fatty acids to the lubricants employed will be realised.

On the other hand, whenever steady relative motion of the rubbing surfaces can be maintained, it would appear to be possible by the

use of a suitable lubricant and correctly proportioned surfaces to set up a condition of film lubrication of the Reynolds type with all the advantages which this system affords.

Further, the vexed question of grooves in bearings which has given rise to so much controversy in the past may now, it is thought, be regarded as settled. It was found by Beauchamp Tower that the presence of an oil groove in the crown of a bearing effectively prevented the formation of an oil film. It has now been demonstrated that in reciprocating motion a liberal amount of grooving to give the oil access to all parts of the bearing surface is necessary for efficient boundary lubrication.

To what extent the values of the coefficients of friction obtained are absolute values for the materials and lubricant employed cannot be stated without further investigation, but it is thought from the results obtained with the plain bearings and journals that the difference is small.

Experiments on the effect of different materials for the rubbing surfaces are in progress.

OIL CONFERENCE AT THE SIXTH INTERNATIONAL MINING EXHIBITION.

An Oil Conference arranged by the Institution of Petroleum Technologists was held at the Sixth International Mining Exhibition at the Agricultural Hall, London, on the 4th, 5th, 7th and 8th June, 1923, the chair at the various meetings being taken by the President, Mr. E. H. Cunningham Craig, Mr. Arthur W. Eastlake, and Sir Thomas H. Holland, K.C.S.I., K.C.I.E.

On the opening day, Monday, June 4th, the President, Mr. Herbert Barringer, M.Inst.C.E., M.I.Mech.E., M.I.N.A., occupied the chair, and in opening the Conference, extended on behalf of the Institution a very cordial welcome to all its guests. The Institution fully appreciated the honour they had done it by attending the Conference, and hoped it would be of mutual benefit to them. It had always been the object of the Institution to exert a world-wide influence, and the International Mining Exhibition gave an opportunity for an exchange of ideas and experiences by means of which further knowledge might be disseminated.

The opening address was then read, as follows :—

The Riddle of the Carpathians.

By E. H. Cunningham Craig, B.A., F.R.S.E., F.G.S.

Under this title it is proposed to discuss the main problems of the oil and gas-fields, or supposed fields, of Hungary, Rumania, Poland, Jugo-Slavia, Austria, and Czecho-Slovakia, in fact all the region bordering the mountain chain of the Carpathians and its associated ranges and the plains enclosed by or surrounding them.

The region may be fairly claimed to be unique on the earth's surface, though in other countries similar phenomena to those observed in certain districts are well known.

There is a great deal of literature on the subject, but it is not proposed to deal with that except in the most general way, but to concentrate upon the problems, tectonic and stratigraphic, affecting the origin and accumulation and underground storage of petroleum.

Many geologists have studied the region, and there has been no little controversy upon theoretical points of great interest. In this conference it is attempted to bring together the latest views and the latest work of practical field geologists of all nations, with the hope that in discussion some at least of the problems may be thoroughly threshed out, and possibly even settled conclusively.

In this short introduction it is hoped that it will suffice to state the main problems to be considered and to introduce briefly the authors of the various short papers contributed.

The main problems, apparently, throughout the whole region are bound up with the subject of salt domes.

These phenomena are not, perhaps, fully understood as yet, and are hardly mentioned in geological text-books: they are known in several parts of the world besides this interesting region, notably in Texas and Southern Persia, but it is certainly in Central Europe that they are most widely distributed and can be studied in every stage of development from the earliest to the latest.

A salt dome consists for all practical purposes of an intrusive more or less circular plug of rock-salt, which heaves the superincumbent strata into dome-shape, but which by slow and long continued action forces its way through the over-lying rocks to emerge as a cylindrical or even mushroom-shaped mass against which the various sedimentary formations are successively sheared off.

These salt masses, therefore, introduce a complication in tectonics by giving evidence of local vertical upward pressure, and the various combinations of this vertical pressure effect with the normal effects of tangential pressure are the cause of very complicated geological structures.

Salt domes certainly seem to be developed along the lines of folding or incipient flexuring due to tangential pressure, but in regions at some distance from orogenetic action the vertical pressure is the more important and beautiful circular or oval domes are formed, while in and bordering the mountain ranges where tangential pressure is high, the salt masses may be drawn out and sheared into lenticular form overturned and thrust among recumbent folds. Every stage can be studied in this region.

The problems of greatest importance are:

(1) The origin of the salt masses.
(2) The age of the salt.
(3) The relative importance of vertical and tangential pressures.
(4) The association of the salt with petroleum, whether essential or adventitious.
(5) The age of the petroleum (including gas).
(6) The origin of the petroleum.

Satisfactory answers to these problems will have the effect of making the search for new oil or gas-fields a matter of great simplicity, and are, therefore, greatly to be desired in the interests of science and industry.

In this introduction the writer is anxious to be entirely impartial as to the various theories put forward, reserving for the subsequent

discussion any views he may have to offer on particular points. In the meantime, it is sufficient to indicate the views of some of the principal contributors to the discussion.

With regard to (1) and (2) there are two main theories, first that the salt has its origin in Tertiary strata, and the second that it has a much older and deeper source. The former has been almost universally accepted till recent years by Continental geologists, and will be supported by Dr. Hugo de Bœckh: the latter will be championed by Professor Voitesti and others.

(3) will be dealt with at length by Dr. Maximilian Kraus, and (4), (5) and (6) will be dealt with by many contributors, some upholding a vegetable origin for the petroleum and others an animal; some tracing an essential connexion between salt or brine and oil, and others holding that the role of salt masses is merely structural and that the association with oil is merely accidental.

It will be seen that a complete knowledge of the stratigraphy and the tectonics of the region is necessary if we are to arrive at any definite results. Probably no one observer has sufficiently detailed knowledge of *all* the districts in this region, but many have studied three or four, while others may have only worked in one or two of the countries considered, but may be in possession of illuminating evidence from other regions.

The attempt is to get *all* the evidence available together and to discuss it fully.

Oil Deposits and the Tectonics of Vertical Pressure

(With special reference to the Oilfields of the Rumanian Pliocene.)

By Dr. Maximilian Kraus.

(Read by Mr. E. H. Cunningham Craig, in the absence of the author.)

Some nine years ago an article in a technical journal suggested to the writer that vertical as well as tangential forces play an important part in tectonic processes. It explained the subsidence of loaded ground and the upheaval of adjacent unloaded areas, familiar during the construction of highways and railways upon loose soil, as follows: (see Fig. 1). The loaded part of the ground, A, is

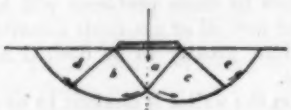


Fig. 1.

compressed and forced downwards, parts B and C move sidewards, while D and E are shifted both sidewards and upwards, the resulting thrust-curve having the form of a logarithmic spiral. E. W. Shaw's paper on "The Mud Lumps at the Mouths of the Mississippi" was a further valuable contribution to the subject. In both cases the movements are ascribed to differences in vertical pressure, but, whereas, in the first, dislocation *en bloc*, giving rise to so-called "Listrical Planes," takes place along thrust-planes having the form of logarithmic spirals, in the second (Fig. 2) there is rather

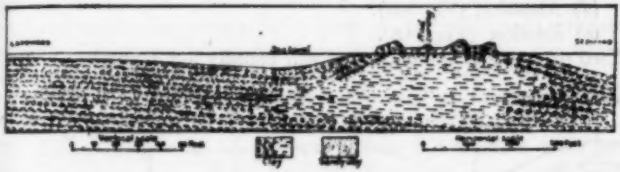


FIG. 2.

a flow of material from the point of maximum to that of minimum vertical pressure, resulting in anticlines the limiting planes of whose cores are also logarithmic spirals. (Posepny's "swan's neck curve," Fig. 3.) The problem is a large one and cannot thoroughly

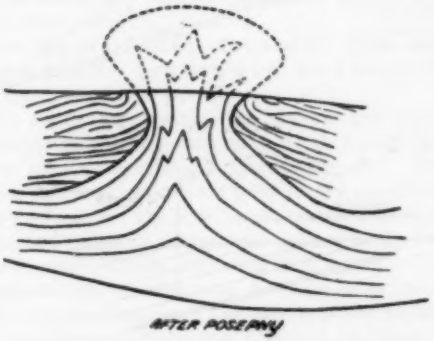


FIG. 3.

be dealt with here. The writer can only consider the chief conclusions which he has reached during his study of the tectonics and origin of the principal Rumanian oil deposits.

I. Principles of the Tectonics of Vertical Pressure.

1. That movement may take place, the differences in vertical pressure must be great enough to overcome the internal friction of the material.

2. Pressure differences may be due to :—

(*a*) Folding (Fig. 4A).

(*b*) Fractures and other points of weakness in the crust of the earth (Fig. 4B).

(*c*) Differences in thickness of sediment from unequal sedimentation (Fig. 4C).

(*d*) Abrasion (Fig. 4D).

(*e*) Erosion (Fig. 4E).

Two or more of these factors will usually act together.

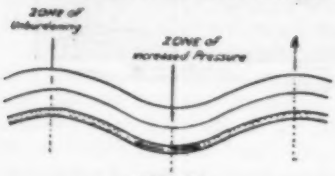


Fig. 4A.

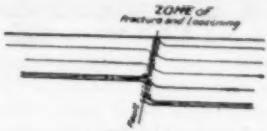


Fig. 4B.

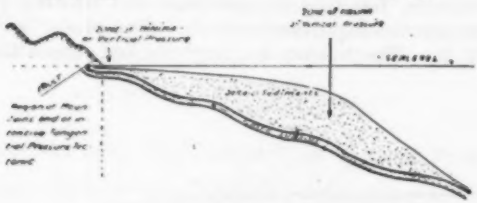


Fig. 4C.

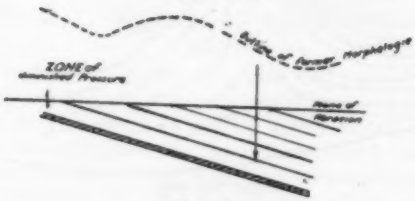


Fig. 4D.

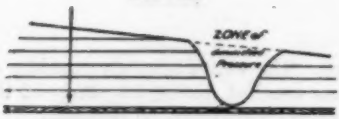


Fig. 4E.

3. Marls, clays, and sands which are naturally plastic, or materials such as salt which can become plastic, are most apt to form anticlines under the operation of vertical pressure. Rocks of high resistance and cohesion can do so only when they undergo folding without fracture. Saturation with oil or water favours movement. Differences of specific gravity play a minor part and affect the result only in so far as low specific gravity in an up-thrust mass makes for less back pressure in the rising arm of the spiral. That the thrust-planes which bound salt-cores in vertical pressure anticlines display the logarithmic spiral form particularly clearly is due, not to the low specific gravity of the salt, but to its peculiar faculty of combining great solidity with plasticity through recrystallisation. Difference of specific gravity thus favours the action, but is not indispensable, as is shown by Figs. 1 and 2.

4. The thickness of sediment subjected to vertical pressure affects the result.

5. Great differences of pressure acting for a short time only may have little or no effect, while small but prolonged differences may produce a great one.

II. Characteristics of Structures Resulting from Vertical Pressure.

The degree in which the above factors enter into the reaction, and the number and position of maxima and minima of pressure, determine the structure. Anticlines formed in this way show the following features:—

1. Their cores are formed of material which has migrated under pressure, and has been forced up, the younger sediments on the flanks playing a passive part.

2. In the final stages the core pierces the younger strata (Mrazec's Diapyrism), and comes into contact with them along a plane curved into a logarithmic spiral (Fig. 5A). It should be remarked that this curve is *concave* towards the maximum pressure.

3. In the early stages the core forms merely a low ridge beneath the lightly arched anticline of younger sediments, and the angle of dip diminishes outward from the core (Fig. 5B).

4. The dimensions of the spiral surfaces of a core may vary widely within a short distance. The aspect of any particular cross-section will thus depend upon the direction in which it is taken (Fig. 5A) and the amount of erosion the anticline has undergone (Fig. 6).

5. When maxima are arranged in a circle around a minimum, the core is bounded on all sides by spiral thrust-planes, and assumes the form of a cauliflower (Fig. 3). The points and lobes are caused by the overlapping of several spirals.

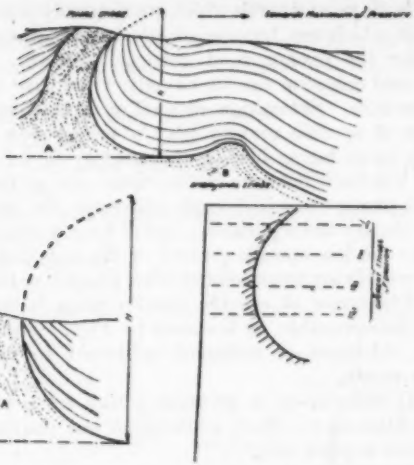


FIG. 5. FIG. 6.

6. One-sided arrangement of the maxima and minima gives rise to oblong domes, whose cores are thrust or tilted over the younger sediments, according to the number and position of the maxima (Figs. 7, 8, 9 and 10). Figs. 8, 9 and 10 show clearly how

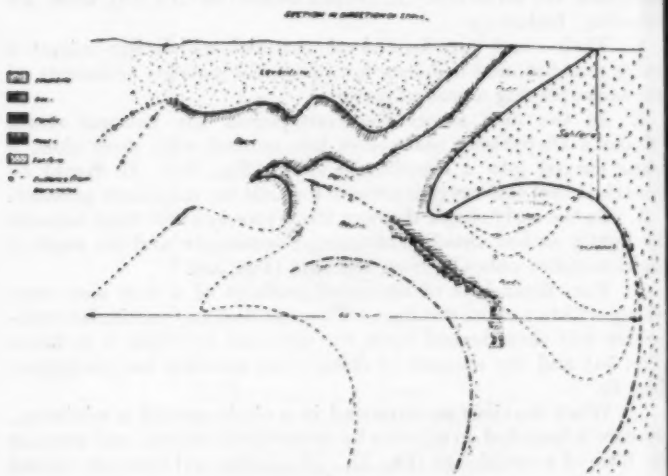


FIG. 7.

Fig. 8.

Fig. 9.

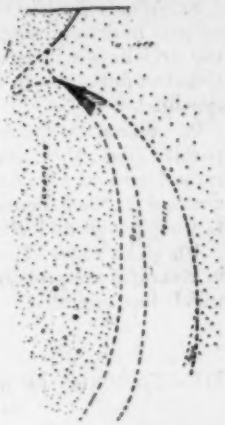


Fig. 10.

the violent action of the core may drag out, laminate, or even rend the younger sediments.

7. Parallel spirals close together give the impression of scale-structure (Fig. 11).

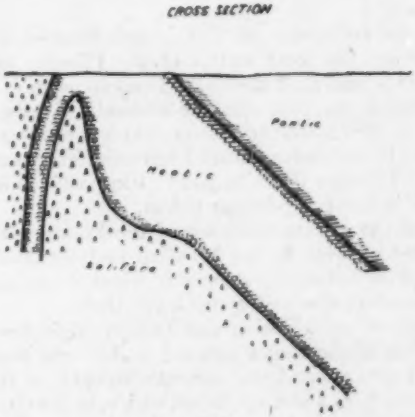


Fig. 11.

8. Where the effects of previous tangential pressure play little or no part in determining the formation of vertical pressure anticlines, the anticlines will have but little extension in the line of strike. Between anticlines in the same line of strike, the structure will be synclinal.

9. When the maxima and minima of pressure are arranged in parallel lines, the anticlines will be disposed like the squares of a chess-board on account of interference in directions of thrust. An analogous phenomenon is exhibited by a water surface simultaneously agitated at two adjacent points.

10. The zones of steep dip in the region of maximum pressure in Rumania are probably due to deficiency in the subsoil of material which has migrated.

III.—Tectonics of Vertical Pressure and Oil Deposits of the Rumanian Pliocene.

The foothills of the South Carpathians, east of the Dambovita River, provide examples of these structures which show their connexion with the oil deposits. The formations concerned are the Pliocene (Levantine, Dacian, Pontian, and Mæotian), the Miocene (Sarmatian, Mediterranean, or Salifere), and the Palæogene (Oligocene). Of these, only the Dacian (Tuicani, Ochiuri, Baicoi) and Mæotian (Bustenari, Campina, Filipesti de Padure) in this region yield oil in quantity. The Oligocene is productive only where it has been in contact with the Mæotian (Bustenari) and the Salifere is very poor. Small quantities of oil have been found in the Sarmatian.

The Pliocene sediments are deltaic and show clear signs of the conflict between the fresh waters of the Pliocene rivers and the salt or brackish waters of the sea. The extension of the fluviatile Levantine sediments indicates the ultimate victory of the fresh water, and there is reason to believe that where the rivers are now characterized by extensive Diluvial terraces their position coincides with that of Pliocene rivers, a point of importance in oil geology, since it aids in localising former deltas.

In view of the deltaic character of the Pliocene, the restriction of the richest oilfields to the Mæotian and the Dacian, and the occurrence of oil in the Oligocene only where it has been in contact with the Mæotian, the writer concludes that:—

1. The oil of the Mæotian and Dacian originates in the outer zones of deltas of these ages and not, as hitherto supposed, in the Salifere. The rivers and sea currents brought to these zones an abundant microflora and microfauna, which, in the altered biological conditions, died and were precipitated and covered by the colloids

of the rivers coagulated by the salt water. In the course of time a great quantity of organic matter was thus accumulated.

2. Sedimentation above these deposits, due to the slow but continuous subsidence of the Rumanian geo-syncline, proceeded more rapidly on the outer than on the inner edges of the deltas.

3. The thickening cover of sediment brought the organic remains into regions of higher temperature and pressure, where they were transformed into oil and, at the same time, set up vertical pressures which were greatest on the outer and least on the inner edges of the deltas.

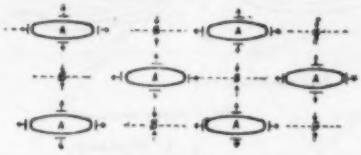


FIG. 12.

A = *Anticlines.* S = *Synclines;*

Lateral charging into contrary phases and chessboard-like distribution of vertical pressure anticlines and synclines resulting from interference of the directions of thrust.
After Posepny.

4. The coincidence between the position of maximum pressure and that of deposition of the oil rock caused the subsoil of the delta and the oil which originated there to tend to migrate in the same direction, in this case, northwards. In the Mæotian, the tectonic and mineral-forming processes started simultaneously, but, in the Dacian, the migrating oil met with vertical-pressure anticlines whose cores had already penetrated and passed the formation. The differences between the Mæotian and Dacian deposits can thus be explained.

5. The southward progress of the deltas shifted the maxima of pressure in the same direction. More or less parallel rows of anticlines were thus formed, of which the northern are older than the southern.

6. The cores of anticlines, which had passed through oil-bearing formations, acted as dams on whose southern side the oil coming from the south accumulated (Fig. 14).

The peculiarities of the Rumanian deposits are explicable in the light of the above considerations.

The oil-bearing tract of Bustenari-Campina-Pucioasa, about 45 km. long (Fig. 17), lies to the north of the best known and most productive oil region, and contrasts with the series of "brachy-anticlines" in the south. It corresponds to a plane of dislocation due to tangential forces to which it owes its extension along the strike. The earliest anticlinal movement of the Salifere, due to

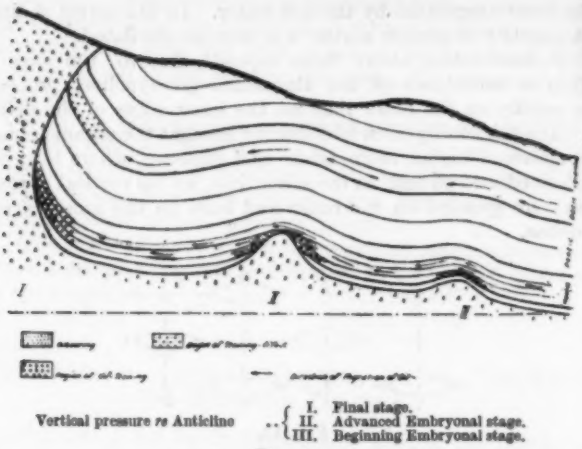


FIG. 14.

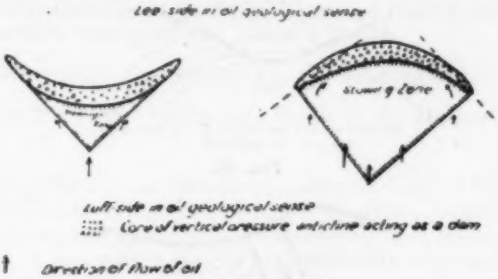
vertical pressures, availed itself of this line to form a long ridge, bordered in cross-section by spiral thrust planes, against more or less the whole extent of which the Mæotian oil was caught.

The brachyanticlines in the south were under no constraint from pre-existing effects of tangential pressure, and are consequently short in the direction of strike. They show the chessboard type of distribution which could only occur in the practical absence of older structures. The arrangement of the anticlines in rows lying approximately parallel to the Bustenari-Pucioasa line seems to show, however, that preceding tangential action has had some influence, presumably through slight folding of the Salifere subsoil or the production of the marginal fractures which are common during the formation of geosynclines. Both folding and fracture promote the development of minima of vertical pressure (see Part I., 2*a* and *b*), and may, therefore, to some extent, determine the position of its structures, even though the formation of the anticlines is due to other causes such as, as in this case, unequal sedimentation.

It is likely that, further south, where the effects of tangential pressure are probably absent, the arrangement of the vertical pressure anticlines would be different. On account of the simultaneous commencement of the vertical pressure process and the formation of oil, even the early stages of the anticlines contain Mæotian oil (Filipesti de Padure, Ceptura), and it is also found in the Mæotian strata on the northern flanks of anticlines in the final stages (Moreni-Bana). When the Dacian oil was formed and

migrated, a series of anticlines in the final stage already existed, against the southern flanks of which it accumulated and formed rich deposits (Fig. 14). It is only found on the northern flanks in so far as it was able to flow round the plunging ends of the anticlines (Moreni-Tuicani, Moreni-Bana). The flow of oil was not impeded by the shallow arches of immature anticlines, which are consequently practically barren in the Dacian (Filipesti de Padure, Boldesti).

The capacity of anticlinal cores for accumulating oil depends on their form (Figs. 15 and 16). Those whose convex sides face the


lee side in oil geological sense
stowing zone
luff side in oil geological sense
Core of vertical pressure anticline acting as a dam
Direction of flow of oil

FIGS. 15 and 16.

flow of oil have less effect than those presenting a concave surface (Tuicani).

The strikingly curved, garland-like form of certain cores of the Rumanian brachyanticlines (Fig. 17. Baicoi, Moreni, Glodeni)

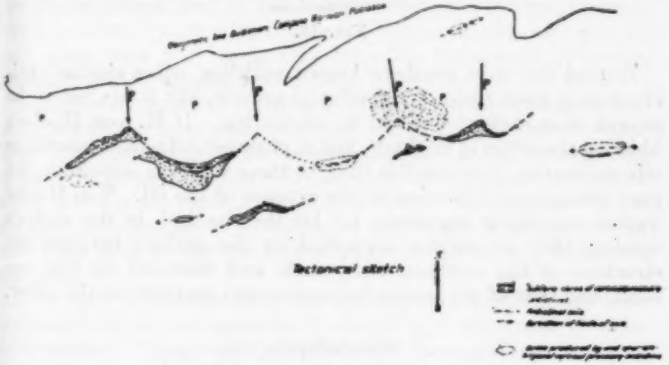


FIG. 17.

are the result of differences of tangential pressure which may produce spiral thrusts in the horizontal plane as vertical pressures do in the

vertical. Tangential forces are thus seen to have been in play during the Pliocene although so feebly as to require great time to produce visible effects. The plastic material rising in the vertical pressure anticlines came under their influence and was thrown into these garland- or sickle-like forms.

It will seem curious to many geologists that, in Rumania, it is particularly the open anticlines, with outcropping cores, which are rich in oil, whereas such structures are usually unfavourable. The explanation lies in their mode of origin. (Figs. 18 and 19).

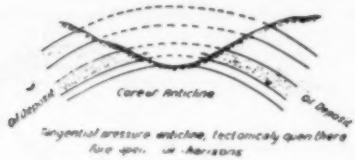


FIG. 18.

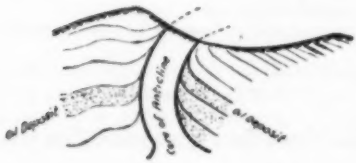


FIG. 19.

Beyond the most southern known anticline, other similar anticlines may exist beneath the diluvial gravels, but it has yet to be proved that they also would be oil-bearing. If H. von Hoefer's ideas on the origin of methane, and naphthene and naphthomethane oils are correct, it is possible that, in these southern anticlines, the gas content would increase at the expense of the oil. Von Hoefer quotes convincing arguments for his theories and, in the writer's opinion, they are further supported by the analogy between the structure of the methane compounds and diamond on the one hand, and that of the benzol derivatives and graphite on the other.

CONCLUSION.

Every serious industry must be founded and managed on a scientific basis, but the scientist cannot dispense with theories and hypotheses which, like the thread of Ariadne, help him to grope his way through the labyrinth of Nature's riddles. It is his constant

task to test his deductions against observed facts. The solutions proposed in this paper to the problems which arise in connexion with the Rumanian oil-deposits are based on observation and deductions therefrom, and it is the writer's hope that they will serve as a useful and correct foundation for further work on the same subject.

Note on the Genesis of Hydrocarbons and their Localization in certain Zones of the Earth's Crust.

By R. D'ANDRIMONT, Hon. Professor to the Belgian Colonial School.

(Read by Mr. E. H. CUNNINGHAM CRAIG, in the absence of the author.)

I MUST apologise for the extremely condensed form of this statement. It is, indeed, impossible to treat so wide a subject in the concise way imposed by the rules of the Congress, and the arguments in support of my opinion can be presented only very summarily.

For the same reason, all references to previous work, and to the bibliography of the subject, are excluded. I believe, however, that I shall be meeting the wishes of my friends on the Organisation Committee if, nevertheless, I give my own views on this important question.

Carbon, hydrogen, and oxygen are simple bodies of relatively low atomic weight, and, on this account, are found diffused throughout the exterior part of the globe. They have such affinities for each other that they constantly form the framework of matter necessary to the appearance of life.

Animal and vegetable organisms, at all times, have fixed carbon, either directly or from such compounds as CO_2. They have tended to fix it in the relatively stable molecules of $Ca\,CO_3$, and $Mg\,CO_3$, in those huge accumulations of limestone and dolomite which are found in the outer parts of the earth's crust. The existence of life has also promoted the combination of carbon and hydrogen, giving rise to the series of unstable bodies which are found in hydrocarbon deposits.

From this brief statement we see that organisms must have produced comparable amounts of organic and calcareous or dolomitic matter. Compounds of carbon and hydrogen are, however, far less stable than carbonates, particularly when, in the exterior part of the earth's crust, they come into contact with atmospheric oxygen; so that at, or near, the surface carbonates are much more plentiful than petroleum.

Compounds of carbon and hydrogen may be divided into two great groups :—

(1) Organic compounds related to cellulose.

(2) Organic compounds which belong to what may be called the fatty bodies.

All débris of dead animals and vegetables contain variable proportions of these two groups of compounds.

Much previous work has shown how transformation into peat is effected, and that it is more or less complete, according to the amount of oxygen that can reach the deposit. It is also known that those accumulations in which cellulose predominates exhibit most clearly the progressive transformation of organic matter into coal and anthracite.

The processes of organic transformation into coal and hydrocarbons are regarded as parallel, and of the same kind, but as taking place under different chemical conditions. Several factors intervene to determine whether the final product shall be petroleum or coal. These factors are:—

(1) The proportion of cellulose to fatty matter.

(2) The conditions of the place of deposit, leading to rapid or slow change, and complete or incomplete protection from the action of oxygen.

(3) Pressure, temperature, and time.

The predominance of one of these factors may make up for the lack of another. In particular, if a geological formation is carried deep down into the earth's crust by folding, pressure and temperature may compensate for poverty in fatty matter, and thus effect the hydrogenation of carbon and of matter rich in cellulose.

At the same time, most hydrocarbon deposits must have been formed at the expense of organic accumulations rich in fatty matter, at depths at which pressure and temperature have played equally important parts.

Generally speaking, then, the tendency is for vegetable débris to be transformed into coal, and animal matter into hydrocarbons.

But the existence of extremely oily (*gras*) carbonaceous deposits, whose origin must certainly be sought in accumulations rich in fatty matter, and, on the other hand, of hydrocarbon deposits—which I can describe verbally during the course of the Congress—whose primary matter has indubitably been vegetable matter with predominant cellulose, justifies us in admitting exceptions to the rule.

Qualities of Hydrocarbons.

It is most probable that the qualities of hydrocarbons are determined by :—

The quality of the primary matter.

The duration of the process of transformation.

The pressure and temperature to which the deposit has been subjected.

The kind of formations traversed by the migrating liquids and gases.

The primary matter must have accumulated as organic débris, pure, or mixed with carbonates, or with inert matter, such as clay or silica, brought in by water.

Our habit of referring all magnitudes to the standard of our own stature has made it difficult for us to conceive the possibility of tectonic movements over great distances, whereas, relatively to the dimensions of the earth, such movements are, in fact, small.

We make the same mistake in connexion with the migration of hydrocarbons through the earth's crust ; but, just as we admit the possibility of movement of bodies of water—and particularly of captive waters, such as artesian supplies—over great distances, so we must recognise that, by the intervention of factors that we shall examine later, hydrocarbons also can migrate.

In the course of migration the hydrocarbons will meet with different mineral matters. Reactions with the bodies encountered will lead to chemical modifications ; the degree of permeability of the formations will cause physical changes ; and osmosis and catalysis will occur.

Generally speaking, deposits furthest from their place of origin will be most profoundly modified. Those still involved in clayey or shaly matter will be in proximity to their place of origin, perhaps even *in situ* (bituminous shales). Deposits in porous matter, such as sand, may be far from their place of origin, and retention of the heavy hydrocarbons by the various filtering media through which they have passed, may lead to the predominance of the light hydrocarbons.

Tectonics of Deposits.

The principal cause of migration is folding of the earth's crust. This arises in feeble, easily deformed zones through the approach of resistant blocks, which, moving towards each other with different velocities, produce asymmetrical chains. Folding commences in depth and is first manifested at the surface by a bulging of the crust. Later a chain arises and erosion begins : the altitude

continues to increase as long as the rapidity of the bulging is greater than that of erosion. It is also important to note that, after the consolidation of the core of the chain by the piling up of the formations, the folding extends further from the axis, that is to say, in front of the true chain, in the direction of its inclination.

In the final stages of a chain of mountains, the formations in front of it have a folded, complicated, and faulted structure, but are not much metamorphosed. Although violently dislocated, they remain unconsolidated. This is because a relatively feeble overburden, during the whole period of tangential pressure, has allowed them to escape upwards. Under these conditions diapyrism occurs, and masses of specially plastic materials such as gypsum and salt come to the surface.

In the final stages also, are produced the normal faults which bring about another kind of dislocation. These faults may be transverse to the direction of the early folding. The normal subsidences due to them often begin at the periphery of the chain, and are propagated subsequently towards the axis.

It will be seen that the transformation of organic matter cannot be accomplished at the axis of a chain in the same way as at the periphery. At the axis, deposits of organic matter will be subjected to intense metamorphism, that is to say, to considerable pressure and temperature. The enclosing rocks, however, being relatively hard, migration will be impossible, particularly to masses of organic matter rich in cellulose.

Deposits rich in fatty matter—tending to produce hydrocarbons—will either remain *in situ* involved in difficultly permeable material such as shale, thus forming bituminous shale, or, if in very permeable formations, will tend to be expelled towards the periphery.

In the regions in front of mountain chains, which undergo late folding, conditions are quite different. Although the overburden of formations above the deposits and the lateral pressure may be less, some parts of the deposit will, nevertheless, be carried to considerable depths where, with the aid of heat, transformation into hydrocarbons will be accelerated. The rocks only slightly metamorphosed, and relatively unconsolidated, will constitute good reservoirs, particularly formations of sand or sandy marls, but their very characteristics will permit migration, especially along faults or diapyric accidents. The hydrocarbons will easily migrate from one reservoir rock to another according to the pressure to which they are subjected.

As soon as the axes of mountain chains are consolidated and elevated, conditions become favourable to littoral and deltaic sedimentation in which all the organic products of the elevated chain will be received. The formation of hydrocarbon deposits of this type, whose existence is otherwise proved, is thus explained.

I think that the considerations I have just mentioned, although very briefly, are sufficient to explain the position of most hydrocarbon deposits in relation to mountain chains, and their analogous situations, in relation to the axes of folding, in Morocco, Algeria, Spain, the south of the Pyrenees, Galicia, Rumania, and the Caucasus. All these deposits are at equal "tectonic distances" from the zones of folding.

As to the detailed localisation of deposits I shall content myself with saying that present theory leads us to seek them for preference along zones characterized by faulting and diapyrism, and that, in the deposits themselves, the classic superposition of gas, hydrocarbon, and salt water, is met with.

Deposits are also found, but more rarely, which are not in the immediate neighbourhood of fractures of the earth's crust. In these cases, the hydrocarbons have been able to flow laterally to a considerable distance from the fissures on account of the permeability of the formations.

The Mode of Appearance of the Petroleum Deposits in the Carpathian Regions

with

General Considerations on the Genesis of the Petroleum and the Salt of the Actual Deposits.

By Dr. I. P.-Voitesti,

Professor at the University of Cluj (Rumania).

1. Generalities.

A characteristic feature of the petroleum (hydrocarbons of petroleum) that forces itself universally upon our attention is the generality of its occurrence in almost all kinds of rocks known on earth (and even in some meteorites), and in almost all the geological formations from the Palæozoic up to the Quaternary, on the whole surface of the continents and the islands.

This generality of its extension leads us implicitly to the admission of genetic causes that must be quite as general as this generality of its occurrence, and from that we arrive implicitly at the elimination of all hypotheses explaining the genesis of the petroleum by particular geological phenomena, or by special geological facies, the limited development of which cannot explain this characteristic feature.

Thus, the bringing into connexion of the genesis of petroleum with the presence of some facies having a limited extension, like the lagunar or the deltaic, or with the presence in some strata of certain organic remains, or lastly with that of certain chemical

combinations, all this cannot explain in any case the generality of its occurrence. Consequently the discussions on the genesis of petroleum must be directed another way, in order to get a satisfactory explanation of this feature.

2. The Petroleum of the Rumanian Carpathians.

In these regions the petroleum does not appear in particular connexion with any special rocks or geological formations constituting those regions, because we find it from the Lower Cretaceous up to the Quaternary in all the porous or fissured rocks of all the formations constituting the Flysch of the Carpathians as well as the formations of the Sub-Carpathians and the Transylvanian basin. Thus: in the Aptien of the Carpathian Flysch the petroleum was exploited at Frasin (Körösmezo) at the sources of the Theiss, in the mountains of Maramuresh, and in the form of sources it springs up in the Southern Carpathians, in the same formation at the sources of Teleajan (at Cheia), as well as under the peak of Siriu, in the torrent Rosu, on the right side of the Valley of Siriu, and in the Valley Vulpea (Prahova); in the Upper Cretaceous (Cenomanian) it was exploited with shafts at Maciucu Bertea (Prahova); in the Eocene it is exploited in the Eastern Carpathians (Lucacesti, Moinesti, Nineasa, Chitlae, Mosoare, etc.), as well as in the southern ones (Vârfurile, Breaza de Jos, Cosmina, Chioj du Mare, etc.), and in the north-east of Transylvania (Dragomiresti); in the Oligocene it is exploited on the whole length of the border of the Carpathian Flysch, from Poland (Boryslaw-Tustanowice), passing over Bukovina and Moldavia (Doamna, Solont-Stanesti, Zemes, Moinesti), until Muntenia (Wallachia) at Bustenari; in the Miocene it was exploited in the Southern Carpathians (Govora, Glodeni, Ocnita-Poiana, etc.), as well as in the eastern ones (Tescâni, Câmpeni Parjol), and in Transylvania there appear numerous traces (Ocna Sibiului, Cetea, Toga, etc.); and lastly in the Pliocene of the Southern Subcarpathians, in Mæotian and Dacian are found to-day the richest exploitations of petroleum of Rumania (Ochiuri, Moreni-Bana, Filipesti, Vf. Drăgănesei, Baicoi-Tintea, Câmpina, Bustenari, Bordeni, Păcureti, Arbănasi, etc.).

But if the petroleum of the Carpathian regions does not appear genetically connected with some special geological formation, its deposits in any of them are intimately connected with the tectonic of these regions. To disregard this fact and to bring the petroleum of the Rumanian regions in connexion with certain facies or stratigraphical formations, as some geologists try to do, is a fault due, I think, only to the misunderstanding of these tectonic relations.

For, indeed, the only positive data we know up to the present about the occurrence of petroleum are those concerning the tectonic

conditions in which we find it, that may be summed up in the following words; the occurrence of petroleum as well as the deposits formed by it, are closely connected with certain zones and lines of dislocation (fractures and more or less fractured folds), and the petroleum may be found in all porous or fissured rocks, that are able to store it in some form, and belonging to any geological formations, with the only condition that these rocks should have been directly affected by those dislocations. And between the fractures accompanying the borders of the great tectonic unities (Carpathians, Sub-Carpathians, etc.), along the whole chain of the Carpathians, we have very numerous instances that may exemplify regionally this statement, especially where zones of fractures or fractured folds affect at the same time the zone of the Carpathian Flysch and the Mio-Pliocene of the Subcarpathians (the zone between the sources of Oituz, Târgu-Ocna and Moinesti, in the Eastern Carpathians and Sub-Carpathians, and the zone between Buzău and Dâmbovita in the southern ones), and in which all the geological formations from the Cretaceous up to the Quaternary become petroliferous by coming gradually in touch with them, and on more or less extended distances around those fractures. Of course, these zones of fractures are much more obvious in the Cretaceous-Nummulitic formations of the Carpathian Flysch, because the Flysch is directly supported by the old basement of the Carpathian regions, the fractures of which have influenced its dislocations; they are less obvious in the Mio-Pliocenic formations of the Sub-Carpathians on which these dislocations have slighter effects, sometimes scarcely felt, on account of the plasticity of the materials and of the great thickness of intermediate strata that separate them from this fractured basement.

An important characteristic feature of the petroleum deposits of the Carpathians is the close connexion that may be observed between the formation of the productive deposits and the situation of the salt domes along the same zones of dislocations. This connexion which was thought to be peculiar only to the Carpathian regions, seems to have a much more general character, after the new studies that were made in North Africa, Asia, Spain, the Balkan Peninsula, Jugo-Slavia, Germany, etc.

At least for the Carpathian regions this tectonic connexion between the situation of the salt domes and that of the richest petroleum deposits may be explained in the following manner: the location of the petroleum in the present deposits as well as of the salt masses in the salt domes, issuing from the depths (the old basement ?) against the upper regions of the earth, was effected at once and under the influence of the same tectonic movements (end of the Pliocene—beginning of the Quaternary), both utilising the same fractures. There, where these fractures have been much

widened by the salt masses, the migration of petroleum could be effected much easier, and in this way its accumulation in greater quantities was facilitated near the borders and the extremities of the salt masses, in the porous rocks that came in direct contact with the fracture and whose porosity was increased by mechanic actions (breaking, driving back, etc.).

Leaving aside the nature of rocks, which may have an important influence, the forms of the petroleum deposits depend first of all on the force of dislocation which the movement of the fractures of the basement had upon the formations of the Mio-Pliocenic overlying it, and afterwards on the widening and increasing of porosity effected by the salt masses, in their piercing through, on the formations that were affected by this action.

In the regions where the action of the deep fractures did not affect the whole thickness of the new overlying strata, they are folded like large anticlinal domes (the right "diapire" folds of Mrazec), in the core of which are found the more or less vertical strata, these alone being affected by the action of the fracture (Fig. 20, A). If these anticlinal crests rise higher in some regions,

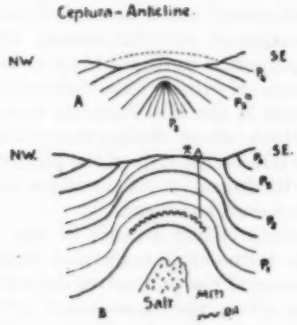


FIG. 20.

A Anticline's extremities.
B Anticline's dome.
M Miocene.
P_1 Maeotian.
P_2 Pontian.
P_3 Dacian.
P_4 Devantine.

they acquire the form of more or less symmetrical domes, in which the petroleum may be equally distributed, forming a symmetrical deposit.

On the distances where salt masses pierce in their core, remaining nevertheless at fairly great depths, the almost horizontal strata of the dome under the pressure of the salt masses are separated from its flanks by their extension and flattening (Ceptura) (Fig. 20, B). the flattening arriving sometimes to a breakage of both flanks (Arbănasi), or of one of them only, the sunken one (Filipesti de

Pădure) (Fig. 21); in these cases the deposit is more and more asymmetrical.

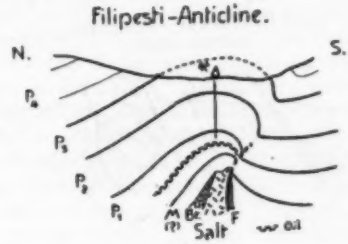


FIG. 21.

M Miocene.
P1 Maeotian.
P2 Pontian.
P3 Dacian.
P4 Levantine.
Br Tectonic breccia of rock salt.
F Fracture.

In the places where these newer formations were stronger affected by the said tectonic action, and are folded in anticlines, either right or asymmetrical, or in flexures, but completely fractured, and these folds have been cleft here and there on short distances by the salt masses, the petroleum deposits are also more and more asymmetrical, both flanks being productive, the sunken one (the inverted) being nevertheless richer imbibed, not only quantitatively, but also on greater distances (the region of Pliocene of the Southern Sub-Carpathians: Ochiuri, Moreni-Bana (Fig. 22), Baicoi-

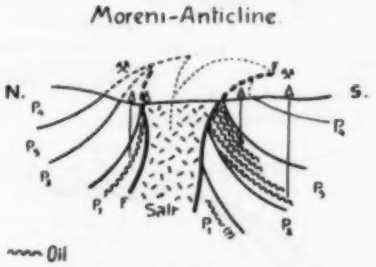


FIG. 22.

P1 Maeotian.
P2 Pontian.
P3 Dacian.
P4 Levantine.
F Fracture and overthrust.

Tintea, and in the Carpathians at Mosoare, Păcurita, etc.). When these fractured folds have passed to little overthrusts (the Southern Sub-Carpathians—the zone of Miocene and the inner border of

Pliocene: Vârful Drăgănesei (Fig. 23), Câmpina, Bustenari, etc.), the asymmetry of the deposits is so pronounced that the right flank is very poor, and only the inverted one is productive.

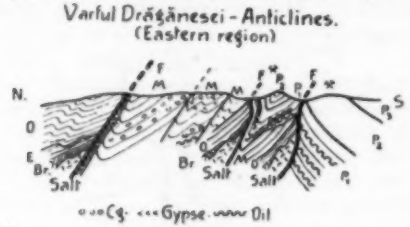


FIG. 23.

E	Eocene.	P_3	Pontian.
O	Oligocene.	P_2	Dacian.
M	Mediterranean.	Br	Tectonic breccia of rock salt.
P_1	Maeotian.	F	Fractures and overthrusts.

However, if the overthrust along the fracture is so strong that the direct flank passes very much (500 m.–2000 m.) over the inverted one (in the zone of the Carpathian Flysch: Zemes, Moinesti, Solont-Stănesti (Fig. 24), Boryslaw-Tustanowice (Fig. 25), etc.;

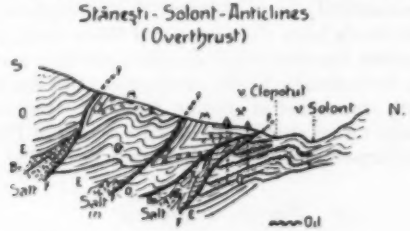


FIG. 24.

E	Eocene.	Br	Tectonic breccia of rock salt.
O	Oligocene.	F	Fractures and overthrusts.
M	Mediterranean.		

FIG. 25.

E	Eocene.	Tr	Quaternary.
O	Oligocene.	Br	Tectonic breccia of rock salt.
M	Mediterranean.	F	Overthrust.

in the zone of the Sub-Carpathians at Câmpeni-Pârjol, etc.), the inverted flank only, seized underneath, contains petroleum, the direct one, on the overlapping area, lacking even traces of petroleum. These overthrusts are generally in relation with the sinking of one flank (the inverted one) and, as a rule, the flank that is turned against the outer side of the zone of the Carpathians or of the Sub-Carpathians is the sinking one. Nevertheless, the cases in which also the inner flank is sunken and overlapped are not seldom (the region of Mosoare Târgu Ocna in the Eastern Carpathians and the anticline Apostolache-Salcia in the Southern Sub-Carpathians) and even, along the same fractured anticline, sometimes the outer flank is sunken and overlapped (Părăul Tudorache), and sometimes the inner one (Părăul Adânc, Eastern Carpathians, jud. Bacău), and that on a distance of a few kilometres.

3. Considerations on the Genesis of Petroleum.

Seeing that not only in the Carpathian regions, but in many other petroliferous regions of the world (Alsace, Germany, Africa, Mexico, etc.) the connexion between the existence of profound fractures, extended over whole regions, and the location of the petroleum deposits is more and more evident, I hope that the future geological investigations will prove that we are right in generalising our proposition about the Carpathian regions—namely, that the genesis of petroleum cannot be brought in relationship with any one of the formations in which it is found accumulated on a secondary way. Indifferent of its origin, which may be inorganic or more probably organic, its migration from great depths to the surface of the earth, along the zones of deep fractures, extended over great regions, the frequency of which cannot be doubted by anybody, agrees fully with the generality of its occurrences, quite indifferent of the nature of rocks and the age of the formations.

In this direction, I think, might be turned with success the investigations about the genesis of petroleum. And in this order of ideas, if we admit that it comes from great depths, may its origin not be due to a phenomenon of incipient regional metamorphism of the formations of the geosynclinals, which, after beaking and sinking during the more recent geological times, are in a continual period of gradual sinking? These sedimentary formations, rich in organic remains (especially of plants), sunken at greater depths, under the influence of a continually increasing heat and pressure, may have undergone a gradual distillation, which will have brought forth the hydrocarbons of petroleum from the organic substances contained in those sedimentary formations. The same causes may have urged their slow migration along the fractures against

the upper regions of the earth. We might admit that during the long periods of apparent rest of the sunken portions of geosynclinals, the hydrocarbons brought forth by this slow gradual distillation may have been accumulated under the influence of pressure in the porous rocks of the deeper regions, and afterwards when the tectonic movement of the fractures began again, during the renewal of the orogenetic movements, the fractures being reopened, the hydrocarbons of petroleum may have been forced to an ascendant migration in great quantities, being again accumulated under pressure in the porous rocks of the anticlinal domes which have not been completely split by these tectonic movements, as well as in those of the deeper formations that came in contact with the fracture, forming thus, after the shutting of the fractures, rich deposits accessible to drilling.

This hypothesis agrees better not only with the laboratory experiments of Engler and his collaborators, but also with the generality of the occurrence of petroleum and the hydrocarbons of petroleum on the whole surface of the earth, in all kinds of rocks, with the only condition that they should be porous or fissured, so that they may store it in some form, indifferently of the origin and the age of the geological formations in which these rocks are contained.

4. Considerations on the Connexion between Salt, Iodine and Petroleum, and on the Age and Genesis of the Rock Salt.

The connexion between salt and petroleum, as we have shown it another time,[1] is only tectonical, not also genetical, as some geologists admit, and it is due only to the fact that the salt masses have utilised the same fractures as the petroleum, in their ascension against the surface, urged by the same tectonic movements.

It is very probable that the waters that, properly speaking, accompany the petroleum (the "veteric" waters of Mrazec), as well as the iodine they contain, should have been distillated at the same time with the hydrocarbons of petroleum of the same formations. It is also possible that a part of the chlorides of the original marine waters, that are still contained in these sedimentary rocks

[1] I. P.-Voitesti.—"Sur l'origine du sel et les rapports sectoniques des massifs de sel avec les gisements de pétrole de Roumanie." B. S.-G. Fr. (4-e) t. XXI., pp. 48-57. Paris, 1921.

"Considérations sur la Géologie du sel des massifs des régions Carpathiques." C. R. du XIII. Congr. Intern. de Géologie. Bruxelles, 1922.

"Rapports géologiques entre les gisements de sel et ceux de pétrole." Annales des mines de Roumanie. VI-e Année, Bucuresti, 1923.

of the geosynclinal in the depths where the temperature of distillation arrived to 700°–800°, and especially NaCl, should have taken part at this distillation; but the majority of the salt waters that are found in the petroliferous regions of the Carpathians, forming more frequently strata alternating with those of the petroleum, are due only to infiltration, and have taken their salt through dissolution from the salt masses in their neighbourhood, and the iodine from the iodureted waters of the petroleum deposit, with which they came in close contact during the play of the fractures, at the beginning even of the location of the petroleum deposits.

As for the age of the salt domes, I have shown it evidently elsewhere (1 and 2) that, seeing their tectonic mode of appearance, which is the same in the Carpathians and in the Sub-Carpathians, they being like long oval crests cleaving along the lines of fractures all the Cretaceous-Quaternary formations which are brecciated by them (Fig. 26), they not only cannot be considered as Miocenic

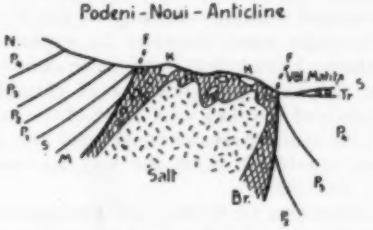


FIG. 26.

M	Mediterranean.	Tr	Quaternary.
S	Sarmatian.	Br	Tectonic breccia of rock salt.
P_1	Maeotian.	K	Block-klippes of crystalline rocks and schists, of Jurassic-Neocomian chalk, of Eocene and of Oligocene.
P_2	Pontian.	F	Fractures and overthrust.
P_3	Dacian.		
P_4	Levantine.		

(1st Mediterranean), as it was admitted up to date, but the salt is older than the whole complex of Mesozoic-Tertiary formations of the Carpathic regions. The actual position of the salt masses being only tectonical, and not at all stratigraphical, it cannot give, in any case, an indication about the age of the salt. As I pointed out another time (1 and 2) it is a great mistake which is being made elsewhere (Africa, Spain, Germany, Austria, Poland, etc.), when the age of the rock salt is deduced from the age of the oldest geological strata between which it is enclosed nowadays, or from the fossil-remains or the pieces of fossiliferous rocks found in the tectonic breccia around or even penetrated in the interior of the rock salt mass; because these remains and broken pieces originated, through crushing, from all the rocks of the formations that were pierced by the rock salt in its ascendant movement, with the predominance

of the elements originated from the formations in which it is enclosed.

The fact that the rock salt, generally considered, has, like the petroleum, the same character of universality, being squeezed along the lines of fractures, through which it pierced from the depths, between the rocks of almost all formations, and on the whole surface of the earth; this not only explains the close tectonic connexion between the location of the present salt deposits and those of petroleum, but leads us implicitly to the elimination of all hypotheses bringing in connexion the genesis of rock salt with wholly accidental geological phenomena and consequently of a too limited development (concentration lagoons, continental salt lakes, desert or steppe lakes, etc.).

Besides this general tectonic feature, seeing also the enormous quantities of pure and crystalline salt, accumulated in the innumerable rock salt masses known nowadays on the whole surface of the earth, we expressed the opinion (1) that the rock salt cannot be brought into genetical relation with any of the known geological formations. Its origin must therefore be explained in another manner, and namely, I think that it might be done bringing it into connexion with the huge precipitations of chlorides, that took place on the surface of the first solid crust of the earth, when the temperature of its atmosphere, charged with the vapours of all those substances, combined or on the way to combination, had decreased until 700°–800°.[3]

In this case the action of water, that precipitated much later, when the temperature had fallen and the influence of which is shown through the stratification of the rock salt, was reduced only to the separation, by way of dissolution, of the various chlorides, and afterwards their sedimentation through re-crystallisations from the solutions, in the existing excavations of the first crust. This phenomenon of dissolution and re-crystallisation may have been repeated innumerable times on account of the temperature of the rocks of this first crust, that was still too high, and caused the scarcely precipitated water to re-evaporate. Consequently the salt could not form permanent deposits until the temperature of the crust was so low that it could allow the formation of the first permanent water covering, when the first sedimentary rocks began to settle down, forming thus the first protecting covering of the salt.

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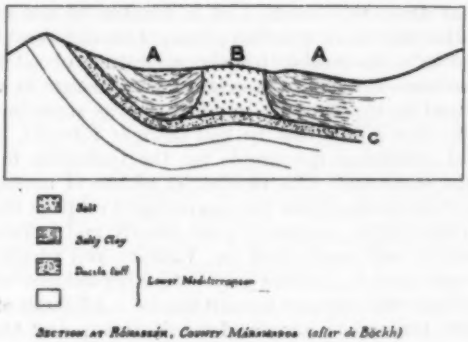
[2] I. P.-VOITESTI.—"Quelques remarques sur l'âge du sel des régions Carpathiques." B. S. C. Fr. (4–e) t. XIX., pp. 84–100. Paris, 1919.

[3] H. DOUVILLÉ.—"Les premières époques géologiques." C. R. Ac. Sc. Paris, 1914.

DISCUSSION.

Mr. E. H. Cunningham Craig said that three papers, all more or less connected and dealing with the subject of the riddle of the Carpathians had now been read, but before throwing the subject open to discussion, he desired to say a few words on behalf of some of the holders of the older theory which Dr. Voitesti had completely upset in his paper. Personally he had had the pleasure of accompanying Dr. Voitesti over a great deal of the ground to be discussed; he had also gone over a great deal of the ground in Croatia with Dr. Papp, and over a great part of Hungary with Dr. de Boeckh. He knew the views of both those gentlemen, and later on when he took part in the discussion he would mention them; but for the present he merely wished to point out that the facts placed before the Conference by Dr. Voitesti entirely upset the theory of the Miocene Salifère. Most of those present would remember that the theory of the Miocene Salifère was embodied in all the text books, and sections were published in books upon oil that were absolutely physically impossible, and that no geologist could understand. When it was realised, however, that instead of it being Miocene Salifère it was salt breccia and salt mass of possibly entirely different ages, all those difficulties had been resolved.

He wished to take the opportunity of showing a slide (Fig. 27) he had received from Dr. de Boeckh, showing a very important section on the borders of Transylvania, which, if it was correct, would be a very serious obstacle to the acceptance of Dr. Voitesti's theory.



Section at Rámnicu, County Máramaros (after de Böckh)

FIG. 27.

The theory was that A was saliferous Miocene, and that B was a mass of salt which had been aggregated by tangential and vertical movement so that it had taken up the position shown. C was a bed of dacite tuff, which was known to be at the base of that Miocene, and the fact of the dacite tuff being there made it obvious that the salt could not be earlier than the dacite tuff. Personally, he could not see that the section was physically possible, but he showed it because the section had been made specially in order that Dr. de Boeckh's views might be represented. Dr. de Boeckh's view also was that the oil was formed from microscopical organisms which existed in the salty clays. Those matters, he hoped, would be dealt with in the course of the discussion.

Mr. Thomas Dewhurst, in opening the discussion, said he confessed that, after reading the papers, he still placed himself in line with the older geologists. He thought that during Tertiary times there were several transgressions and regressions of the sea in the region of the Carpathians, and that those transgressions, and particularly the regressions, offered facilities for the formation of oil at several stages. He thought that this consideration, and a further one which he would shortly mention, met the great objection upon which Dr. Voitesti's case was based, namely, that the oil was of very general occurrence throughout the whole of the Tertiary series. He believed, in the first place, that oil was formed at quite a number of different stages throughout Tertiary times. It was difficult no doubt, to say exactly what those stages were, and the difficulty which had beset Dr. Voitesti was that the whole question had been complicated by the subsequent migration of the oil from the several oil-measures in the Tertiary sequence. He maintained that, owing to the repeated transgressions and regressions of the sea, not only were the conditions favourable for the formation of oil, but that they also resulted in a number of unconformable overlaps. His experience was that planes of unconformable overlap were particularly favourable for the migration of oil from one series to another—*i.e.*, from the original oil-measures in which the oil was formed to the deposits in which it was sometimes found. Therefore the two points that he had brought forward, firstly the repetition of conditions favourable for the formation of oil, and secondly, the occurrence of a number of planes of unconformable overlap which would facilitate the migration of oil from the original sources to other rocks, explained quite clearly and sufficiently the difficulty which had confronted Dr. Voitesti, and which he tried to explain and meet in another way. Another subject even more controversial was the origin of the salt domes. All kinds of theories had been put forward to account for salt domes, and that might be some excuse for suggesting another hypothesis. He did not

think that vertical pressure due to superincumbent beds having been deposited in a geosyncline was sufficient to start any movement in a mass of rock salt below. In the first place, he was of opinion that rock salt was an ordinary chemical precipitate, an ordinary stratified rock bedded in the usual way.

Mr. Cunningham Craig asked Mr. Dewhurst what age he thought it was.

Mr. Dewhurst said he must leave the answer to that question to those who knew the Carpathians better than he did. The view he took was that the only force which could move a thick bed of rock salt from its original position to the positions in which it was now found was lateral pressure; but it was extremely difficult to explain how lateral pressure moved the salt from its original position to the salt domes. He thought in most cases in which salt domes occurred the rocks were not very highly consolidated—*i.e.*, the other rocks apart from the salt. He took the view that the salt was much more rigid than the clays, shales, and sandstones with which it was associated, and that when lateral pressure first began, the beds above the salt, which yielded much more readily than the salt, were the first to yield to the movement, so that folding occurred in these beds. After that he thought there was a pause, because the upper beds had yielded, and the salt below had not yielded owing to its greater rigidity. As the pressure increased, a stage was reached when the salt bed itself gave way to the pressure, even to a greater extent than the overlying sediments. It seemed rather singular that that should happen with so rigid a substance, but when it yielded it presumably became plastic or viscous. It was conceivable that the conditions resembled those pertaining to volcanism, the salt acting like a viscous lava. There were beds above, which had previously yielded; there was a lapse in time; then the salt bed yielded and acted as a plastic or fluid substance, resembling lava in this respect, and the great pressure was sufficient to force the plastic salt through points of weakness in the overlying rocks, exactly as occurred in the case of volcanic action.

Mr. Ashley Carter said that he spoke entirely as a layman, and not as a geologist. He thought it would prove of interest to the meeting if Mr. Craig could give an explanation of the formation of the salt domes. Could it be explained by the application of the theory of the triangle of forces? Could he also state what pressure was exerted and what were the pressures which gave the resultant force in the direction indicated?

Mr. Cunningham Craig, in answer to Mr. Ashley Carter's question, said that he had examined a certain number of salt domes which he admitted had been a very great puzzle to him. He

discovered that the salt domes always originated and came up along the lines of it might be merely incipient folding, but it was always along the lines of folds formed under tangential pressure.

In the same way it was obtained under even more gentle conditions of pressure in Hungary, where there was a sort of chess board arrangement such as Dr. Kraus had described. He had never, however, found salt domes forming where there was not some tangential pressure to start with. Having started them, he thought the idea was that the salt, which was light, but which was not soft, but which, because it could dissolve and re-crystallize, could move just as ice could move by regulation, just as under metamorphic conditions limestone could flow, thickened out on the anticlines that were just forming, and once an anticline was formed the pressure was less over it and, therefore, the action became automatic. Once it had started it became automatic, and allowing the pressure to go on the result was that, supposing there was a thick bed of salt below, a round or oval mass forced its way up. Simply by its homogeneity it was able to force its way through all the other rocks, shear them off against its edge, and finally emerge at the surface. He believed that could all take place (and in that respect he disagreed with Dr. Kraus) under tangential pressure alone; but if that tangential pressure went on further, instead of getting a round salt dome or an oval salt dome, if the rocks were submitted to very strong tangential pressure, a mass was deformed into a narrow lenticle. Along a line of discontinuity there was almost bound to be a tremendous thrust on the boundary of the salt mass. That was one point on which he differed from Dr. Voitesti, because he maintained that it was the mass of the salt drawn out into that shape that had caused the fault, and not the salt that had come up along that fault. That was a point to which he hoped Dr. Voitesti would reply. He knew salt domes existed in Persia, and he hoped something would be said about them in the course of the discussion.

The President (Mr. Herbert Barringer) said that lateral force and vertical force had been alluded to. Lateral force or tangential force might be generated by vertical force. Were there any indications of purely lateral force or some disturbance of the earth's crust whereby a lateral thrust might be obtained without a vertical one—*i.e.*, a sort of squeezing up laterally of the crust?

Mr. Cunningham Craig replied that that was what happened. As soon as sufficient lateral thrust was exerted incipient anticlines were obtained. If there was a mass of salt below, the incipient anticlines would begin to form themselves into salt domes.

The President inquired how the lateral thrust was generated.

Mr. Craig said it was believed that the lateral thrust consisted entirely of a gradual shrinkage of the whole skin of the earth, so that once a mountain chain started to develop it had the whole force of the contraction of the surface of the earth to assist and continue the movement.

The President said that contraction would apparently relieve thrust; but he supposed it increased it in certain quarters and relieved it in others.

Mr. Craig replied that that was so. It increased it along certain lines where the mountain chains developed.

The President said it was generally understood that a shrin- of the earth's crust would not produce lateral force, but just the reverse. Shrinkage ought to do away with lateral thrust.

Mr. Craig replied that it was the shrinkage of the core to which the skin had to adjust itself.

Mr. J. P. Harley said he had not had the opportunity of examining for himself the complicated structures and conditions seen in the Carpathian oil regions. He had read about them, and it had been a real pleasure to him to hear the papers read by so many recognised authorities at that conference. His study of the subject of oil had led him to believe that the same broad principles of oil formation applied to all the oilfields of the world, that the processes of oil formation in one field were in no way different from another. The material from which the oil was eventually formed might have varied in different places; in one it might have been mainly cellulose, in another there might have been a larger proportion of fatty matter, but the processes of the formation of oil did not alter. Prof. d'Andrimont was of opinion that, generally speaking, the tendency was for vegetable debris to be transformed into coal, and animal matter into hydrocarbons, but he (the speaker) could not see that they had any reason for adopting that hypothesis, as they knew that either coal or oil might be formed in nature from vegetable or animal remains, or from a combination of both. Prof. d'Andrimont agreed that that was so, and Mr. Harley thought they were safer and surer of getting to a right conclusion, if they accepted the idea that oil might be formed from either vegetable or animal material, if the right distillation conditions were there. If those conditions were interrupted or broken, the resulting product might be one of the many qualities of coal, or it might be torbanite, dependent entirely on the stage to which distillation had gone at the time of the interruption. The principal feature which

made the Carpathian region so much of a riddle was the presence of salt domes, and their close connection with oil concentrations. Probably the domes were formed by tangential pressure, but they still had to find out the reason of the presence of such a body of salt, and they also wanted to know how far, from which place, the oil had migrated to the anticlinical foldings lying on the central salt core. He did not know the locality, as he had stated, but it seemed to him that a hypothesis could be suggested which would fit the facts. Many times he had had to adopt that method in his work. Given a certain set of conditions, what combination of causes could have brought them about, bearing in mind the fact that the simplest, most obvious causes were probably the most correct. Firstly, they knew that the salt originated in a strata below the oil, as the oil rocks were well up on the central salt core. Secondly, he thought they might safely assume that at the time the salt domes were forming, at the time when tangential or other pressure was being applied, there was no oil at those particular points. Thirdly, a region might be assumed—possibly with concave strata—which had been desiccated, accounting for the immense amount of salt, in which pressure raised the whole country and raised the salt domes in particular parts. The oil might have been—it was quite reasonable to assume that it was—on the edges of the region of desiccation, and when the country with the salt domes was raised, the oil would migrate to the new anticlines, as he was of opinion that oil might migrate for very long distances if no insuperable barrier intervened.

Mr. C. G. Sara said he did not propose to say anything directly about the Carpathians, but as he had had something to do with the salt deposits in Egypt he desired to take part in the discussion. There could be no doubt that in Egypt the salt deposits were part of the stratagraphical sequence and that they were not derived from any hypothetical deposit of chlorides deposited in times that possibly never existed. The deposits in Egypt were generally thin. On the island of Gaysoom there was one bed 300 ft. thick, but the majority of the beds were round about 10 to 20 feet thick, and they alternated with gypsums and shales. The beds were situated on the flank of an anticline or a hemi-dome. One or two places existed in Egypt in which very thick salt bodies were obtained. He had detailed personal knowledge of one of those places. At Jemsa, in the centre of the dome, a thick salt deposit existed. At Ras Dhib there was considerably over 1000 feet of salt. That salt was not on the flank of a dome, but in the centre of a very low flat dome which came off the major axis of the country. He had no information as to how that thick salt formed, for instance, whether it was due to the thickening up of the thin salt beds by lateral

pressure. He rather doubted whether it occurred in that way. He thought, as a matter of fact, it was a primary deposit. That was all he wished to say with regard to salt.

Coming to the general question of oil origins, he thought Dr. Voitesti was quite right in directing attention to the relation of oil-fields and tectonics, but he very much doubted that the origin of oil could be so completely separated from the strata containing it as he suggested. Might not the tectonic changes which went to form geosynclines or fractured areas not only open up fissures to admit the petroleum into the reservoir, but also lead to the formation of deposits containing sufficient organic matter to make the petroleum itself? In other words, might it not be that the tectonic changes permitted of the deposition of the petroleum mother deposits rather than open up the channels from such deposits? His reason for suggesting this was that in the Maikop field there was no reason to believe that the accumulation of oil could possibly be due to the tectonic conditions of the field. He was aware that there was a theory that the oil came up along chalk cliffs, but that was an antiquated and exploded idea. It actually occurred in an oil-sand which was contained in the old river valley, and so far as he could state after three years' study of the subject, there were no faults in the district. Underlying the oil-sand there was a white marl which was elevated and eroded before the oil-sand was laid down. That marl could hardly be the mother rock of the oil because it formed an eroded land surface before the oil-sand was deposited. Over the oil-sand there was a darkish sand containing fish remains and other carbonaceous matter, so that one was really driven to two theories in Maikop—either the oil percolated up through a great thickness of marls between 1000 or 2000 feet, or it came down from the fish scale and leaf beds. Personally, he thought it was the latter, because he could not imagine that oil would strike up through the marl. He thought in Trinidad the light oil deposits must be considered as being derived from the rocks which contained the sands. It was true that the light oil deposits in Trinidad were very closely connected to big tectonic lines, but when it was borne in mind that the lenses contained oils of a very different chemical character, and that those oils were not found mixed in any one lense, he could not believe that the oil had migrated from any distance, but he thought it was probably derived from the shales in immediate contact with the sands.

Mr. W. M. Cranston said that a well put down on the south-west flank of the anticline at Jemsa went down over 3000 feet, practically through solid salt, except for thin bands of gypsum, and was abandoned. The productive wells at Jemsa were on the

north-west flank of the breached anticline. At Mulhaimet Island, where drilling was now going on, some two miles east of Jemsa, a certain amount of salt had been met with, but the salt and gypsum series had been bottomed at 2300 feet.

Mr. W. G. Weeks said he was rather disappointed that nothing had been heard, during the meetings of the Congress, of other salt domes and salt masses than those that existed in Rumania and Egypt. There was a number of salt domes in the American Gulf Coast region, whose origin, he could not help thinking, must in some way or other be similar to that of the Rumania domes. If that was the case, then the study, not only of the resemblances of those two sorts of domes, but also of their differences, would help to decide what were the essential features of those occurrences, and what were only chance attributes due to local conditions. It seemed to him that the principal problem to be solved was the origin of the salt, because if the theory happened to be right that the salt came up from a basal region, all the arguments about vertical and tangential pressures would be rather beside the point. There was an American theory that it was derived from ascending solutions. Whether that was right or wrong he did not know, but supposing it was right, a sufficient reason existed for the salt occurring in those great masses without going into the question of whether they were due to vertical or horizontal pressures. As, however, the question had been raised, he desired to make one or two observations on the relative importance of those two pressures. He thought on a small scale—*i.e.*, within a very limited area in which sediments could be regarded as homogeneous, something like Dr. Kraus's movement might possibly take place. He remembered a case in Siam in which difficulty was experienced in constructing a railway embankment over recent deltaic deposits, because the embankment subsided, and the ground, some yards away inside the rice fields, used to go up. In that case something like Dr. Kraus's theory might apply, but, on a large scale, it seemed to him that the irregularities in composition and form of the deposits must play so large a part that, even if a logarithmic spiral did exist, it would be distorted beyond all recognition. The distribution of salt domes was very strongly suggestive to him of a deep-seated origin. So far as he had been able to follow it, there was an increasing tendency to regard volcanic products, not so much as part of a supposed sea of molten matter, upon which the earth's crust was reposing, but as the contents of magma-pockets in which old sediments might be re-fused. Now, if among those old sediments there were thick beds of salt, or beds rich in salt—and it was known they occurred in Palaeozoic rocks—it seemed to him possible that, when the factors favouring fusion came into play, the salt would

fuse at a temperature far below the fusion point of the other constituents of the beds, and would form an extremely liquid melt, able to take full advantage of any points of weakness, such as fault-intersections, in the overlying cover. Even if in the original deposit it was mixed up with clays and sands, the molten salt would automatically come out in a more or less pure form. He had no doubt that the theory he had expressed presented many difficulties like most of the others that had been put forward to account for the puzzling phenomenon under discussion.

Dr. Voitesti, speaking in French, dealt with the question of the age of the Rumanian salt masses.

They had for many years been regarded as belonging to the Miocene Salifère, and this view had been adopted, particularly by all Rumanian, Czecho-Slovakian, and Polish geologists, very largely on the authority of Suess, who attributed them to the 2nd Mediterranean (the Schlier).

Dr. Voitesti himself had accepted this view up to 1910, on the strength of the occurrence in the Eastern Carpathians and Sub-Carpathians (Bacau-Sarata) of great salt masses under the Cretaceous-Palaeogene Flysch, which could not be explained by overthrusts. Since that date he had studied some 200 salt masses, and the evidence had compelled him to believe that the salt had its origin certainly below the Miocene, and perhaps below even the Jurassic.

He described a number of sections which bore out his theory, giving various examples in which the salt cores penetrated the whole of the Cretaceous-Palæogene-Miocene series. In one case, Podenii-Noui-Prahova, he had found in the salt of a core which penetrated a Tertiary area, large blocks, both rounded and angular of Jurassic and perhaps Carboniferous rocks and of granite and crystalline schists. A very clear example occurred at Bela (Dambovitza), where, on each side of a salt breccia, a complete Cretaceous to Miocene series was exposed. Some light was thrown upon the time when the salt-extruding movements took place by the discovery in a salt breccia in Transylvania (Braid, Corond), of blocks of a Miocene-Pliocene andesite.

Dealing with Dr. Kraus' paper, he remarked that most of his conclusions fell to the ground because he had made the mistake of confusing the salt, the salt breccia, and the Mediterranean. In his opinion, the garland-like form of some of the masses, ascribed by Dr. Kraus to logarithmic spirals set up by tangential pressure, was in fact due to the intersection of post-Pliocene and Miocene lines of folding.

He pointed out that much harm had been done by the theory, for which there were no grounds, that the oil of Rumania was derived

from the Miocene. In this belief, many wells had been abandoned upon proving this formation to be barren when it was quite probable that deeper drilling would have discovered oil.

The Chairman (Mr. E. H. Cunningham Craig), in closing the discussion, said he was absolutely convinced that there was no other explanation possible than the one Dr. Voitesti had given. He had examined the Miocene in Croatia, Hungary, Rumania and many other places, and he had never seen the least sign that it ever was anywhere a saliferous formation. Quite apart from that he had satisfied himself that it was entirely impossible in some of the Moldavian ground for the Miocene to have been thrust underneath the Oligocene and Eocene to such an extent that salt masses could have emerged through the latter; in fact, he thought it might be taken that the Miocene Salifère was dead and buried. The reason why it was first suggested was largely because it was known that in Egypt and in Persia there were saliferous formations in the Miocene, but the very interesting point had now arisen in Persia that there were salt domes there also, and those salt domes did not begin in the saliferous Miocene, but came up at any rate from below Cretaceous. The rocks were broken right through in the formation of salt domes. He was not going to attempt to suggest what was the age of the salt that came up in those extraordinary masses in Rumania. It was certainly older than Cretaceous or than Jurassic. It certainly brought up metamorphic rocks—dark green, not very crystalline, but schists. How old it was he did not pretend to say, but it was certainly not Miocene. That point, as Dr. Voitesti had pointed out, was a very important one. If wells were to be stopped when they entered the Miocene, engineers did not allow themselves any chance of striking oil in the Oligocene and in the Eocene, where it was known that oils occurred in quantities. In that connexion he wished to point out that Dr. Kraus stated twice in his paper that the Oligocene was only petroliferous when it was in contact with the Meotic, but from the evidence he had seen personally on the ground he was prepared to contradict that absolutely, because he had seen it very heavily impregnated with oil where there was no Meotic within miles, and where there could not have been any Meotic because a later Pliocene formation was lying upon the denuded edges of the Oligocene and Eocene. There again he desired to join issue on one point with Prof. Voitesti. First of all he wished to remind him that the Carpathian region was very different from other parts of the world. Dr. Voitesti had suggested that there was some kind of analogy between the Carpathians and Spain and Africa, but he thought it would be found that that analogy was hardly borne out by facts. He further stated that the oil occurred in every part of the Tertiary

It did not occur in every part. It certainly occurred in the Eocene, the Oligocene, in the Meotic, to some extent in the Sarmatian, and in the Dacian, and he had found in the Pontian the actual transition stage between the lignitic and the petroliferous phases. He could prove that, at any rate, some of the oils in the Oligocene, the Eocene, the Meotic, the Pontian and the Dacian, also had originated in those formations, just as Mr. Dewhurst had suggested. He, therefore, joined issue with Dr. Voitesti on those points, and also upon the idea of the migration of oil by faults. He had studied oilfields in other countries which were much simpler and much easier to work, in which it was possible to be absolutely sure of the facts, and in which it was not necessary to put up theories and fight about them for years. It was known in those countries that where oil was obtained in quantity there were generally very few faults. There were no great thrusts nor huge fractures nor masses of salt. Dr. Voitesti's theory of oil and oil migration must account, not only for what he found in Rumania, Transylvania, Hungary and Galicia, but also for what was found in other parts of the world. There were a great many other points he might have mentioned, for instance, with regard to lateral pressure and vertical pressure, which had been dealt with very fully by the gentlemen who had taken part in the discussion.

Oilfield Waste.

A. Beeby Thompson, O.B.E., M.I.Mech.E., M.Inst.M.M., F.G.S.

(Read by Mr. Hubert May, in the absence of the author.)

Oilfield waste has been for years the subject of spirited debates and caustic comments in the United States, where scientists, practical oilfield operators, and conservation enthusiasts have expressed in no hesitating voice their contrary opinions on this much vexed question. There are some whose views are worth more than ridicule, who insist that no unjustifiable waste has occurred in oilfield operations, whilst others emphatically maintain that no industry can show such reckless and irremediable losses as that of oil. Only by a dispassionate consideration of the subject in its broadest aspect can an unbiassed opinion be arrived at. That prodigious losses have been sustained is unquestionable, but whether these were pardonable, if imprudent, or should be placed in the category of deliberate waste is debatable. One is indeed led to enquire what is waste, and if one accepts the definition of waste as the needless squandering or prodigal employment of resources,

we should logically call oil producers practising wasteful methods wastrels or profligates, epithets we should all resent.

Science advances with such rapid strides that the criticism cast on the older oilfield pioneers by our youthful, ardent and imaginative successors appears to them well deserved. It seems almost silly now to look back to the industry twenty-five years ago, when few uses for oil were known, bulk transport was nearly non-existent, and two or three modern deep wells in some of the later-discovered fields would have supplied the bulk of the world's demand ; times when producers sold their product with difficulty for a mere pittance of 1s. per barrel or less, gasoline was burnt as fuel, and certain products of refineries could not be disposed of as a gift. One of the singular events of ancient history is the almost complete ignorance of mankind concerning the occurrence and possible uses of oil products.

Over twenty years' intimate and unbroken association with practical oilfield work in many countries is sufficient to prevent the writer from viewing the subject of oilfield waste in anything but a common-sense manner, and it is from this standpoint that an endeavour is made to present the subject.

Oilfield losses are sustained in many ways : some are unavoidable, some commercially unavoidable, and others are preventable. The unavoidable may become avoidable with the introduction of new methods, and those commercially unavoidable may become commercially avoidable with an advance in prices or the advent of new discoveries or inventions. Preventable losses may continue through ignorance of remedies, conservatism, scepticism, or stringency of finance. Waste or commercially avoidable losses may be conveniently divided into several main heads :—

Ground Waste	Incomplete Recovery. Unrestricted relief of Gas Pressures. Flooding by Water. Emulsions.
Surface Waste	Fuel. Eruptive Wells. Evaporation. Settlement, Drainage and Soakage. Gas and Gas-gasoline losses.
Waste of Energy, Labour and Material	Waste Drilling. Waste of Plant, Material and Labour.

Ground Waste.

Incomplete Recovery.—It is generally agreed that past and present-day methods of oil recovery fail to secure more than a relatively small proportion of the oil contents of oilfields. This loss is variously estimated at from fifty to ninety per cent. of the oil impregnating

the exploitable petroleum strata, entirely excluding the commercially-unproductive oil measures which, in the aggregate, may contain a far larger volume of oil. Under different geological conditions the extraction-ratio varies greatly. Without doubt the most complete extraction of oil contents is from dolomitic limestone, where the oil is secreted in pore spaces of considerable size, and at times in fissures and caverns that impose little resistance to its movement towards points of relief.

The Mexican coastal fields probably present the most ideal conditions for the maximum extraction of oil contents, as, apart from the cavernous nature of the containing strata, the ejected oil is replaced by water and a fairly constant gas-pressure is maintained throughout the whole course of the life of the wells. After some initial irregularity whilst obstructions in the limestones are being cleared, the wells give a sustained production at some determined or tested rate of flow until the underlying water-level rises to within the influence of the well. The flow is then curtailed little by little until useful supplies of water-free oil can no longer be obtained. Then follows a period when the well becomes a stripper, and a more or less emulsified mixture of oil and water is expelled. Except for bodies of oil entrapped in almost isolated patches of limestone, practically the whole oil contents may be recovered. That similar conditions characterise some of the Persian oilfields seems highly probable, and these two countries present the only two cases of this phenomenon known in the oil world.

Elsewhere dolomites have failed to present such conditions, and the yield of oil has gradually tailed off after an initial flush, and has not been followed by flows of water. These limestone wells have characteristics which distinguish them from sand-yielding wells, but they are not exhausted by single flows, and increased yields can often be obtained by various expedients when the output has fallen to an unprofitable quantity.

Oil is mainly drawn from sands interstratified with bands of clay. They are usually lenticles with one pronounced dimension, and where sheet sands cover very large areas oil is usually concentrated in seams or streaks of coarse material rather then impregnating great masses. Just as the yield of water from aquifers is dependent upon the coarseness of grain and continuity of sandy lenticles so is the yield of oil from oil-sands, but in a somewhat exaggerated form that varies with the viscosity of the oil. The reasons for supposing such a small proportional yield of oil from oil-sands are as under :—

(*a*) The quantity of oil raised from oilfields constitutes but a small percentage of the aggregate contents of sands based upon calculated porosities and experimental tests of samples, even when

making great allowance for irregular impregnation, lenticularity and porosity differences.

(*b*) On the assumption that oil and gas occur under approximately similar conditions of distribution and concentration, the volumetric yield of gas-fields appears to be about sixteen times as large as oilfields ; it being realised that gas areas with more widely distributed and controlled wells are exhausted at a rate fully thirty times as rapid as oilfields.

(*c*) There is positive evidence of the small extraction ratio of oil-sands by drilled wells in the re-drilling of presumed drained areas by intervening wells, and the development of so-called exhausted oil-sands by galleries and tunnelling.

(*d*) Increased yields are being obtained from old fields by various expedients, and there are examples where Nature is applying methods for scavenging strata which no longer yield economic supplies by mechanical methods of extraction.

As few oil technologists will deny that the recovery ratio of oil-sands is far below what might reasonably be anticipated, it is their business to aid in devising ways and means of increasing yields.

The following expedients have been, or are being, tested with varying measures of success :—

(*a*) Expelling the oil from oil-sands by water-drive.
(*b*) Activating the remaining "dead" oil with compressed air or gas and then releasing the pressure.
(*c*) Expelling oil by compressed air or gas admitted at strategically-placed wells.
(*d*) Breaking up the harder varieties of oil-containing rocks by violent explosives, thereby extending the influence of individual wells.
(*e*) Applying a vacuum to oil strata.
(*f*) Employing solvents or heat for dissolving obstructing hydrocarbons, or washing out viscous residues that are uninfluenced by gravity or light gas pressures.

(*a*) The water-drive has been so successful in the great Bradford field of Pennsylvania that properties have enormously increased in value, and the new output has not only compensated for the natural fall, but led to greatly increased yields.

Then there are fields like those of Baku, Russia, and the Kern River, California, where the dregs of oil-sands are being obtained from washings by water admitted largely by wells where the upper waters were never effectively isolated.

(*b*, *c*) The use of air or gas for activating oil deprived of its original potential energy in the form of dissolved gas has been attended with very positive success under certain conditions in America, but more co-operation is needed between neighbours,

and its success depends upon very scientific handling of each individual case. Numerous experiments made by the author have clearly demonstrated that oil sources can be re-opened and wells rejuvenated by the judicious employment of high-pressure air or gas. Personal experience indicates that better results are likely to arise from aeration or activation of oil than by air-drive when the oil is carried forward by a rush of air through the sands. By-passing and the traversing of exhausted rather than saturated portions of sands minimises the value of air-expulsion.

(*d*) Perhaps the most effective way of increasing the extraction ratio of compacted oil-sands is by exploding high charges and fracturing the seams of rock. Unquestionably, oil from cemented sands is almost exclusively derived from fissures, just as water is derived under similar conditions; consequently, any action that extended and enlarged the fissure system must inevitably improve both immediate and ultimate yields per unit of area. The utilisation of nitro-glycerine for torpedoing wells has long been in vogue in many American fields where little or no yields may be obtained prior to its use; but within recent years several fields which were regarded as virtually exhausted have been given a new lease of life by the use of explosives which had not hitherto been tried.

Some recent experiments in Trinidad with a less dangerous but violent form of explosive have been quite successful. One well which failed to yield more than a barrel or two daily, and could be bailed dry in a brief time, although almost every known method of inducing entry of oil was tried in vain in the firm belief that the sands were not dry, yielded about 40 barrels of water-free oil daily after a charge had been fired. Another gave a progressive yield to 43 barrels daily over fourteen months, after firing a charge when the yield had fallen to about 7 barrels daily, and twenty-one months after the torpedoing the yield exceeded 20 barrels daily.

(*e*) Vacuum pumping has long been a recognised method of increasing the yield of wells when the gas-pressure had fallen to a low point. There are arguments for and against its uses, but the fact remains that greatly increased immediate yields are obtained by its application. Some technologists question whether the eventual yield of the fields will be improved by its use; but this is probably dependent upon local conditions, which differ considerably.

(*f*) Increased yields have resulted from the application of heat, which may melt solid paraffins or lower the viscosity of some oils which have suffered physical and chemical changes near the dry face of exposed sands, thus impeding the influx of oil from behind. Steam, hot water, hot billets of steel and electrical heaters have all been tried in oil wells, betraying a suspicious depletion curve amidst certain surroundings. These expedients have frequently succeeded

in causing improved yields, showing that the arguments in favour of removable obstructions were correct.

For the same purpose solvents are sometimes admitted to oil-wells, and they possess the advantage of removing soluble obstructions and not leading to the re-solidification of paraffins in a more objectionable form as is possible with melting processes.

Unrestricted Relief of Gas-pressure.—Perhaps the second most important source of ground loss results from the unrestricted relief of gas-pressures. All oilfield workers appreciate the value of gas and gas-pressure as an expulsion agent, and there are few oilfields known where in the initial stages the gas has been insufficient to expel the oil without recourse to artificial methods. The fewer the wells and the wider they are spaced the longer will natural flows continue, thus keeping the extraction costs low and forcing the gas to traverse a longer distance underground. It is only in Mexico, and possibly Persia, that a few strategically-placed wells would exhaust an oilfield. Amongst sands and sandstones there is a limit to the lateral travel of oil and gas, and very varied views are held as to the most economical spacing of wells in each field, and the extent to which yields should be controlled. Different conditions demand different treatment in this respect, and no hard-and-fast rule could be made applicable to many fields. It is, however, certain that had competition not enforced excessive offset drilling in most great oilfields, only a fraction of the wells eventually sunk would have been started. With hundreds, or even thousands, of vents spread over an area of a few square miles it is absolutely impossible to avoid gas losses without performing the work it might be made to do by skilful distribution of wells.

It is certainly questionable whether the control of eruptive wells in all cases does lead to highest ultimate extractions. Most operators realise the risk of checking a large flow in a congested field, but apart from personal advantage there is without doubt a tendency for large gushers to create for themselves a drainage system that would never be formed by controlled flow. Mexican producers always fully opened up their wells for a while to induce a violence which would break down obstructions, and the large lumps of dolomite flung out at such moments testify to the effectiveness of their aim. In Russia and Rumania wells were always controlled with reluctance and misgivings, and world-wide statistical data clearly show that it is the largest initial producers that give the greatest ultimate yields and, if undamaged, have the longest lives.

Whilst unrestricted flow may have its value, it is likely that equally useful results would be achieved by partial control of such wells, thereby saving the enormous volume of gas wasted beyond that necessary to cause ejection of oil. Possibly the periodical

opening up of a gusher controlled through a choker would be even more effective in extending its radius of influence than a continuous open flow with its attendant losses.

Certainly the most deplorable side of oilfield work is waste of gas. During exploration for oil, and during the initial development of oilfields, enormous volumes of gas are lost, as there is little local market for this product, and it is often impossible to reach or develop the oil sources without liberating the associated gas. Means have been devised for shutting off gas-sands entirely isolated from oil-carrying beds, and such measures are now often legally enforced, but there is yet no way of conserving gas that accompanies the oil without some restrictions on drilling and production. The gravest losses are in America, where in the Palæozoic oilfields the quantity of gas is estimated to attain as much as 2000 cub. ft. per barrel, compared with a figure of nearer 250 cub. ft. per barrel for Tertiary oilfields of the lively type.

Notwithstanding all the appeals, warnings and threats little in the way of conservation of gas has yet been done in America, where to-day there are numerous fields daily belching into the atmosphere hundreds of millions of cub. ft. of gas. Glassworks and carbon-black factories chase these gas supplies round, as it is cheaper and quicker to transfer the works than transport the gas, but apart from these wasteful uses and occasional gasoline-extraction plants the gas is dissipated.

Flooding by Water.—Water influxes are probably one of the important causes for large underground losses of oil. There are recorded instances of promising fields having to be abandoned through invasions of water which could neither be handled nor excluded, but these are rare. On the other hand, the water menace in some fields is serious where certain oils will not mix with water, and the geological features encourage the movement of encroaching or entering waters along channels rather than through bodies of sand. Under such conditions watercourses are rapidly carved in the sand bodies to points of abstraction, and bodies of oil are isolated, and perhaps permanently cut off by encroachment of water. Wells so affected may yield mostly water and still evolve large quantities of gas which is performing no useful purpose and freeing the oil-sands of the only energy of expulsion. This, however, is the one problem on which there is least difference of opinion, and in all fields of importance it is receiving the closest attention from both officials and operators.

Emulsions.—As a sequel to the water invasions of oil-sands arises the difficulty of emulsions—the B.S. of oilfield operatives—such as are often formed when gas-agitated water and oil come into contact mixed with inorganic impurities. There are few

oilfields where at some period this trouble has not been experienced. It is no exaggeration to say that many millions of tons of oil have been thrown away by the formation of refractory emulsions. They have sometimes been burnt; at other times run over waste land or into drainage channels. To-day they receive scientific treatment in most fields, and the oil is separated, although at some serious cost. Even old sumps of this B.S. are being examined with a view to possible recovery of oil.

As emulsions are a product of the agitation of oil and water in the presence of a third substance, efforts should first be directed towards preventing the critical condition being reached. Emulsions have been traced to the restricted flow-pipe of a gusher, and to the faulty cups of a deep-well pump; and in Russia to an unsuitable ratio of top and bottom bailing or size of bailer. In some Russian wells they could be induced or prevented at will. Before, therefore, considering remedies preventive measures should be sought by excluding the water, or, if impossible, by such means as checking the gas-flow, modifying the rate of yield, adding to or lessening the proportion of water; indeed, anything which might lead to a variation in the proportion of oil, water, gas and suspended particles or colloidal matter may upset the critical admixtures.

No general method can be prescribed for the treatment of emulsions as they vary so much. The kind of emulsion is influenced by the nature of the oil, the salts in solution in the water, and the character of the suspended material. In one field one process is satisfactory, and in another the same method is valueless. Even the electrical process of dehydration gives totally different results with different emulsions quite distinct from variations of water proportions.

The usual methods of treatment are :—

(1) Electrical dehydration process.
(2) Heating with steam.
(3) Heating to high temperature under pressure in stills.

Surface Waste.

Oil Fuel.—The greatest and often unjustifiable surface waste of oil is in oil fuel, generally replaceable by gas that is allowed to flow into the air. Waste also occurs through failure to adopt economical power methods. Ten to twenty per cent. was no uncommon percentage of the production to be consumed on power generation for its recovery (drilling and production), except in America, where great volumes of gas were generally available at little cost and no inconvenience. In most cases the crude is used direct from the well with its gasoline and kerosene contents, so is a much more valuable product than the fuel oil sold on the market deprived of

its more valuable constituents. Every year this question attracts closer attention, and savings are being effected in the following ways :—

(1) Use of internal-combustion engines (oil and gas).
(2) Use of electrical power.
(3) Topping oil destined for fuel.
(4) Importing a lower-grade fuel oil or coal for steam generation, thus releasing an equivalent of better oils.
(5) Utilising gas from the wells to the fullest extent.

Great waste of oil is occasioned by the unrestricted discharge from eruptive wells. Oil is usually expelled as a spray, in which form it presents the most favourable opportunity for loss by evaporation ; but in addition the portion so lost is the most valuable lightest-density fractions, thereby depreciating the oil considerably for refinery purposes. Flowing oil should be led into one or several gas-tanks or receivers, where under pressure a more quiescent stage is reached, and little oil will be carried away as spray. There are several excellent types of separators now on the market which can deal with large high-pressure flows, even if accompanied by much sand. The gravity of the oil is substantially improved by their use, and their cost is quickly recouped where oils are sold on a gravity basis.

Considerable waste is occasioned by neglect of the smaller intermittent flowing wells or those wells pumping by heads. All such flows are followed by a violent outburst of gas and spray, which may cause the expulsion and dispersion of considerable quantities of oil from the tank or vessel into which the discharge main leads. The losses of light oil may be very great through this agitation in collecting tanks, unless kept under pressure with a loaded valve. All leads from flowing wells and pumps should either be passed through separators, or be arranged to cause a minimum of disturbance in the collecting vessel to which they are conducted.

Leakage, Drainage and Soakage, on oilfields reach large amounts unless all sources of loss are watched. The following are the main sources of waste :—

(*a*) Flowing and bailed oil during drilling and testing operations.
(*b*) Drainage of water and dirt from sedimentation and storage tanks.
(*c*) Leakage of tanks, pipe-lines, pump-glands.

In porous soils much oil may be lost by soakage into the earth, and so great is this quantity in some oilfields that important peasant industries thrive by the recovery of such oil from surface shafts. Generally, however, apart from rainfall, there is considerable surface drainage to conduct from oilfields resulting from drilling wells and

tank drainage, and the main drainage channels become the object of spirited competition for their acquisition. Large amounts are annually collected by enterprising applicants or observers who construct suitable separators to trap the oil washed from the fields. As much as £30,000 was paid to the Government for the right to so handle the drainage of the Yenangyaung oilfield of Burma, where there are perhaps 1000 wells in operation.

Evaporation losses have been brought home to producers by the increasing value of the light constituents of crude. During every movement of oil losses are sustained, and in storage they continue unless the tanks are specially protected against atmospheric influences. As evaporation losses are confined to the valuable light oils the financial loss constitutes a much greater percentage than the volumetric loss as crude. Recent investigations in the American fields indicate losses of between 4·5 and 8 per cent. in the Mid-Continental fields, where the oil is of medium density, and from experience in other parts of the world it is apparent that from 5 to 8 per cent. of the volume, and from 15 to 25 per cent. of the value of crude oils is lost before the oil reaches the refinery or tank farms. The annual losses of gasoline in the Mid-Continental oilfields of U.S.A. are estimated at 500,000,000 gallons between the wells and the refineries. Important savings can be introduced by arranging closed circuits for oil movements and air-tight tanks and receivers with aspiring valves that expel and inhale saturated oil vapours instead of air. Temperatures are kept down in hot countries by using white paints, and sheltering the roof and south sides of tanks with sunshades.

Finally, there is the waste of the highest quality gasoline through failure to extract the more stable condensible constituents of gas before it is used as fuel in engines or under boilers. Over 1,000,000 gallons a day of gas-gasoline, valued at £20,000, are now extracted from oilfield gases in America, and both compression and absorption plants are constantly increasing in number. Most oilfields yield a gas which will repay the extraction of its gasoline content when reasonably near refineries where it can be employed for blending with heavier grades. There are, however, so many factors influencing the successful application of gas-gasoline installations that a sweeping recommendation is dangerous. It is curious how little these plants have been introduced into oilfields outside America, even where the conditions are favourable.

Waste of Energy, Labour and Materials.

Waste Drilling.—A deplorable waste of capital arises from aggressive off-setting in regions where the leases are owned by numerous small proprietors who have disposed of them to many

competing interests or speculators. Respect for customs of antiquity has prevented Governments from interfering with conditions which were admitted to be unsatisfactory, but legislation has been invoked in some cases to remove some of the worst abuses inseparable from divided ownership. Present methods of operating in all fields where the leases are small and differently owned aim at the depletion of other people's land, and it is this desperate anxiety to benefit at the expense of others that leads to such injudicious and antagonistic development of rich oilfields. Still, any projected changes would be vehemently resisted by most existing proprietors, and an improvement can hardly be expected until commercial rivalry is extinguished.

So great is the congestion of wells on some fields that the normal operations are seriously impeded and mutual good will and compromise alone prevent a deadlock being reached. No remedy is possible until all lessees in a subdivided field pool their interests, agree upon a development programme and divide the product according to acreage. Millions sterling are annually spent in unnecessary wells in the great oilfields of the world.

Waste of Plant and Material.—There are such obvious ways of relieving certain burdens without grossly prejudicing individual interests that they should be advocated in every oilfield centre. Mutual co-operation in works which will benefit the whole oil community should be encouraged and supported by operators and officials alike. A few of the schemes in which even conflicting interests could combine are :—

(*a*) Electric stations for generating power on a large scale.
(*b*) Installation of water services for general and fire purposes.
(*c*) Gas-collecting and distributing mains with gasoline extraction plants.
(*d*) Telephone services.
(*e*) Roads, light railways or ropeways.
(*f*) Storages for flush production.
(*g*) Common dehydration plants.
(*h*) Hospitals and social clubs.
(*i*) Analytical laboratory for water, oil and other analyses needed on the spot.
(*j*) Stores for special tools and casing; and standardisation of plant.

Everyone acquainted with oilfield operations must have been impressed by the confusion caused by repetitions of oil, water, steam and gas mains on the surface and lighting and power cables overhead. With each small operator working independently with small inefficient units, costs reach a maximum. In some regions public telephones, power stations, water supplies and gas mains

serve oilfields, thus removing many disadvantages that have to be faced in others. Roads, lighting, fire services and statistical bureaux are sometimes taken over by some public body and maintained by funds supplied by the oil producers as a tax. But more often each operator is left to work out his own salvation in his own way as his resources admit, with the natural consequence that makeshift, cheap, inefficient plant is used by the less opulent with waste of energy, labour and materials. The savings resulting from co-operation in work and co-ordination of results is enormous, and it is pleasing to note the more friendly and helpful relations existing between competitors when forced by circumstances to consult each others' wishes. Amidst congested surroundings no producer can afford to disregard the activities of his neighbour, and legislation often enforces obedience to reasonable demands made in the interests of common welfare.

DISCUSSION.

The President (Mr. Herbert Barringer), in opening the discussion, said the great experience of the author was well known, and therefore any suggestions that he put forward were worthy of most serious consideration. In the first place, he desired to say how greatly he had been struck by the sympathetic manner in which the author had treated the field managers. People were so apt to say that appalling waste occurred on an oilfield, and that they could not understand why the manager did not take steps to remedy it. He thought, however, it was necessary to have a certain amount of sympathy with the man on the spot, because it did not always follow that he was doing what he would like to do. In many cases he had to do what he could under the very difficult circumstances that existed. He thought the author had been very broad-minded, therefore, in not putting too much blame on the field managers, although a great amount of waste occurred on oilfields which could be eliminated. Two schools of thought appeared to exist in reference to the control of a gusher, both of which he thought were probably right under certain circumstances. Occasions occurred on which, by allowing oil a free passage, it might, as a good many Americans thought, open up ground which would not be opened up if too much control was exercised. At the same time other cases had occurred in which there had been a great waste of gas which had exhausted the energy of the well, and the supply of oil had fallen off for that reason. He thought it was impossible to lay down a hard-and-fast rule that a gusher should be entirely controlled, partially controlled, or not controlled at all. The author had further stated that there was no doubt that 10 to 20 per cent.

was not an uncommon amount of surface waste on an oilfield. He could quite understand such a large amount of waste occurring when steam power was used, because there was an enormous waste in the use of steam power through proper lagging not being provided, particularly waste from condensation. He had heard of one case in which something like 50 to 60 lbs. of oil per i.h.p. was used on the field. Where steam was used a great saving might be effected by the provision of lagging of a suitable non-conducting composition. At the same time there could be no doubt that electricity generated by internal-combustion engines in a central station was the right means to adopt. If some of the difficulties which occasionally arose in drilling with electrical plant could be overcome he saw no reason why electricity should not be largely adopted. At present there was a great deal of prejudice against the use of electricity, drillers contending that electrical power could not be used to the same advantage as steam, but he thought that prejudice would, in the course of time, be overcome. The author had mentioned the installation of stations which generated electricity on a large scale. It must be remembered in that connexion that the initial expense and difficulty of getting steam plant up to the wells were very great. Heavy weights had to be transported over very rough ground, whereas if an electrical power station was put in a convenient position it was only necessary to carry a cable to the wells, which could be done easily and quickly. If drillers were in a position to adopt electrical power throughout there could be no question that much of the enormous initial expenditure involved in the laying out of a field would be saved.

Mr. Ashley Carter referred to the two schools of thought on the subject of "choke." Choke in a flow-line had been introduced very largely of recent years, and when it was found that the choke varied so much in size, he thought it would be conceded that no definite result had yet been arrived at in regard to the advantages or disadvantages of its use. There was quite a wide variation in size for a similar depth and diameter of well. The President had also referred to the very interesting question of the provision of lagging. A certain amount of expense was involved if the materials and compositions which were at present in existence were used. One of the most effective and certainly one of the cheapest means of lagging that he had seen adopted on a long steam-line consisted of twisted grass, which was wrapped round the pipe to a thickness of about $\frac{3}{4}$ in., and then plastered to a thickness of perhaps a couple of inches with pure mud, the whole being encased in tin wrapping. The field manager assured him that such lagging was perfectly efficient and that it was a very simple, cheap, and effective substitute for some of the high-priced lagging at present on the market.

Those were little points in connexion with waste which could be very usefully borne in mind. Another very serious point which, in his opinion, had a large bearing on the question of waste in oilfields was the prejudice or bias that existed in favour of one particular method or means of arriving at a certain conclusion. A method of doing things which might have proved quite suitable in one field might be totally unsuitable in another field; in fact, it might be a very wasteful procedure. With reference to the question of the separation of oil and water, to which the author had referred, experiments were being made at the present time with a mechanical separator for the separation of oil and water, and he believed within a very few months full information on the subject would be made public. Another point that should be borne in mind in connexion with oilfield waste was the personal element. Even with the best means that could be placed at the disposal of the oilfield management the personal element always came in, and that alone in some cases accounted for a very great deal of waste. Although various appliances were available, it was only by their practical and correct application that it was possible to expect to obtain full benefits from their use. Another point referred to by the author was the painting of tanks. It was the practice in some very hot countries, in which evaporation was a very serious consideration, to bank the sides of tanks entirely with earth. The thickness of the earth varied according to the size of the tank, and the principle was usually adopted with fairly small-sized tanks only. At the base from 8 to 10 feet of earth were used, the earth gradually tapering in thickness up to the top of the tank. That method was claimed to save a very large amount of evaporation at a small cost; and it possessed the further advantage that it did not require renewal, because once the earth was placed in position it remained there and required no further attention.

Mr. C. G. Sara said that as a geologist the part of the paper which had interested him most was the question of the spacing of wells. That was a very important subject, but it was one on which no rule could be laid down, because it was purely a factor of the geology of the deposit. In a definite deposit it was possible to lay down wells on a triangular system, but in a lenticular deposit that system did not work. It was necessary to follow the lenses, and the distance between the wells was entirely a factor of the type of lens that was being dealt with. A different distance was required if the lenses were going down the dip than if they were along the strike. A great deal of difference of opinion existed with reference to the distance of wells in ordinary normal deposits. He remembered that one company in Russia used to space their wells so closely that it was almost impossible to get in between the derricks,

it being claimed that one well did not influence the other. On the other hand, companies working in lenticular deposits placed their wells so far apart that they lost a very large quantity of their assets. Another question to be borne in mind in connexion with the spacing of wells was the number of oil-sands that were being dealt with. The problem there arose whether a separate well was to be drilled to each sand or whether all the sands could be treated in one well. Personally, he thought each sand, if it had an economic production, should be treated by itself, because with a high pressure and a low pressure sand oil was apt to be lost. That, however, was not always economically possible. In his opinion, this was one feature in regard to which a lot of oil waste occurred. With regard to the question of a well running wild, he desired to mention a point which was very largely geological. If operations were being conducted in a strata which needed to have channels opened up in it then he thought possibly the wells should be allowed to run wild, but in dealing with the ordinary soft sand he was doubtful whether that was necessary, and whether definite flow channels were set up. Such was the case in the dolomites of Persia and Mexico, but whether it was the case in the ordinary consolidated sands he had his doubts. At any rate, the great loss of oil, especially light oil, was from an economic point of view far greater than the benefits derived. He remembered one well which flowed for about six weeks in an absolutely uncontrolled condition, and during that period 30 per cent. of the production was lost. The oil as it came down contained absolutely none of the lighter fractions. In such a case it appeared to him that control of the well was absolutely necessary.

Mr. R. M. Fletcher said the interesting point had been raised of steam drilling *versus* gas- or oil-engine drilling. From his experience of drilling he did not think steam would ever be replaced by the internal-combustion engine. When steam was being used for drilling, first of all there was the motion for lifting up the tools, and the steam engine then let them go directly; whereas with the internal-combustion engine, the compression which occurred had to be met by the downward stroke of the tool, and that took away energy from the tool itself. When a steam drilling-engine was running it brought up the tools slower, and when it went over the centre the tools took the load off the engine, which picked up speed. That could not be obtained with a gas-engine. He had seen drilling done with gas-engines, and it was not successful. That was the chief thing about drilling, which was analogous to taking a drive through a pinion wheel and gear wheel. It was necessary to take a transmission direct from the engine through a belt to the band wheel, and on to the crank, and any rig which was designed

in any other form was detrimental to the drilling. The point raised by Mr. Ashley Carter with regard to the lagging of steam lines really settled itself. The cost of lagging was so great in many cases that it was more than the saving which would be effected. He had successfully carried out lagging in the manner suggested by Mr. Ashley Carter. Lagging consisting of mud and rope and a small galvanised cover over it was effectual for the purpose in view, but expensive lagging, such as asbestos, was not an economical proposition in such cases. The steam-line was down only for a few weeks and then taken away again, and if an expensive lagging was put on the benefit of it was lost. If a temporary lagging was employed it cost very little, and it did not matter if it was thrown away at the end of the job. It was impossible to get native labour out on oilfields to take care of expensive apparatus. He agreed with the remark that had been made earlier in the discussion that the manager did not always do what he wanted to do; as often he had to waive his views for others, to obtain the best co-operation of the staff.

In reply to a question by the President, Mr. Fletcher stated that he had no experience of the use of electric power, compared with steam and the internal-combustion engines, for drilling.

Mr. M. A. Ockenden said Mr. Thompson's paper seemed to deal more or less with established oilfields, but it had to be kept in mind that the chief source of waste was introduced by the small operator and pioneer, who—as stated in the concluding paragraph of the paper—worked independently with inefficient units, the costs therefore reaching the maximum. A number of small operators working together would naturally bring about economy, in the same way as a big organisation was able to introduce efficient methods, but with small operators working separately—unless the State interfered—he did not see how economy could be introduced. The author appeared to suggest that small operators should be, at any rate, encouraged—if not compelled—to co-operate.

The author had not said very much in regard to *methods* of drilling, excepting that electricity should be used if possible, which, however, necessitated generating stations when fields were more or less established. There was a great deal of wastage in the early stages, and a long period must necessarily elapse before it was possible to overcome this.

The President said he that believed a great many oilfields had recently been electrified, and if the author had any figures for electrical working, compared with steam, they would be of great interest to the members.

Mr. Hubert May, in reply, said he desired to emphasise that the remarks he made in reply must not necessarily be taken as representing the author's views. Replying to Mr. Barringer's question about electric power ; a large generating station had been installed in Burma, the chief companies operating in the district having the option to supply fuel for generating power. In very many cases operating companies employed fuel oil as well as gas for power purposes on the field, owing to an inadequate supply of gas. The installation of a central electric power station effects an enormous saving, not only by the infinitely better utilisation of the gas in generating power in one big unit rather than in many small and inefficient units, but permits of an almost constant load factor, and as a result the gas consumed as fuel is much less for the same amount of work done. He was sorry he could not quote figures, but the saving in the fuel bill far more than compensated for the initial capital outlay in installing the plant. In small fields where the companies were not prepared to co-operate and steam plant was already in existence, it was frequently beyond the finances of the companies concerned to scrap existing plant and instal electric power. It was, however, an economy if it could be done. Mr. Barringer's appreciation of the sympathetic attitude of the author towards the men who actually carried out the work was doubtless due to the fact that he had been similarly placed. He knew, therefore, that it was useless simply to criticise, and that any criticism which was made should always be with a view to co-operating to overcome difficulties and not merely to point them out. In order to get over troubles it was necessary to co-operate, and that was one of the underlying features of the paper. Mr. Barringer had referred to the waste that occurred in the use of steam, and had mentioned 50 or 60 lbs. of steam being used per b.h.p. hour, which he thought was very uneconomical. Probably Mr. Barringer would be surprised to know that in some fields in which there were long steam lines as much as 120 and even 150 lbs. of steam per b.h.p. hour had been recorded. One way of eliminating part of the trouble was to instal superheaters and superheat the steam up to some reasonable extent. It was impossible to go to the high temperatures which were possible in a well-designed permanent plant, but if 200 or 300 lbs. of superheat could be obtained it was a great advantage.

He thought there could be no doubt that electric power would be more and more employed for drilling, as it was so much more economical, but except in America, and particularly in California, where he saw several rigs operating electrically during last autumn, it did not yet seem to be generally adopted. The reason was that a great deal yet remained to be learned in connexion with its application. Mr. Fletcher had referred to the point that in a steam-

engine there was a slow lift of the tools and a quick fall, but by the introduction of proper plant that feature could now be obtained with electric power. Very great strides were being made in California in the installation of electric power for drilling, more particularly in rotary wells. For some years past electric power had been used on the oilfields for every other purpose except drilling, and he did not think it would be very long before plant at a reasonable price and easily controlled would be available for that purpose. One of the great advantages of electric power was the ease with which it could be conducted long distances with small losses. The question of standardisation had been discussed for years past. When, however, an attempt was made to arrive at some basis upon which standardisation could be carried out, a few big companies said they were perfectly willing to standardise plant, casing, etc. if their standards were adopted. He hoped that in the future something further would be done in that direction, but it was a very difficult matter to tackle. Even where standardisation was claimed on the part of American manufacturers, for instance, in regard to the interchangeability of drilling tools, it was found in practice that they were not interchangeable; one was too tight, or the other was too loose, so that there was no true standardisation. The plant of two or three companies was, he believed, interchangeable, but it was not universal by any means. The reason for putting a choke on to an oil well was in order that the maximum amount of oil might be obtained from the source with a minimum of disturbance of the oil-sands which accounted for the varying sizes of the choke used in different wells. According to the pressure, the thickness and the coarseness of the sand, so the size of choke was inserted varying between $\frac{1}{4}$ in. and $\frac{3}{4}$ in., which would allow the oil to come away, but would prevent the sands from heaving up into the well. In a recent experience of wells with a very fine sand, a fairly high pressure of gas about 60 lbs. to 100 lbs. per sq. in., and medium quantities of oil up to about 100 to 200 barrels per day, it was found, after experimenting, that a choke about $\frac{3}{8}$ in. diameter gave the best results. With regard to the question of lagging steam pipes, grass and mud could quite well be adopted when the pressure was low. The reason lagging was effective was because of its power to retain air—air being the best insulator that existed—and anything would be more or less efficient according to the quantity of air it retained, it must, however, be protected from wet, particularly in tropical countries. He considered they should not look upon such substitutes as being anything like as efficient as the best types of insulating material on the market. Mr. Ashley Carter had referred to the question of the mechanical separation of oil from water. Some of the emulsions were quite intractable; and even high frequency electric currents had failed to break them

down. If the emulsion could be broken down mechanically there was very little trouble in it, but a true emulsion could not be separated in that way. With regard to the losses by evaporation in tanks, a new idea had come across from the States of covering the surface of the oil with a floating material, which not only reduces fire risks, but also reduces evaporation to a large extent.

Mr. Sara, in referring to the spacing of wells, said it depended upon the shape and size of the lenses. Unfortunately, the wells had to be drilled before it was possible to ascertain how big the lense was, and then it was a little too late, except perhaps as a guide to future work. Lenses followed no law, and they might be dotted about anywhere. Mr. Sara had questioned the accuracy of a statement made that wells placed side by side did not influence one another. Personally he could confirm the statement that that was the case; there were many instances in which such wells did not influence one another. He knew of two wells, one of which was sunk down to a thousand feet, and from which large quantities of oil were obtained. Another, almost touching it, was sunk to the same depth and gave no oil but when it was sunk a further 500 feet a gusher was obtained. Conditions varied in different fields. He entirely agreed with what Mr. Sara had said on the question of shallow and deep drilling. A number of reverse pulleys had been designed, some of which were satisfactory, but the same flexibility was not obtained as with the steam engine. Although he agreed with Mr. Fletcher in that respect he would very much like to see some serious tests made with internal-combustion engines in conjunction with suitably-designed drilling plant. On the other hand, as he had previously stated, he thought electric power would produce the results. With regard to Mr. Ockenden's remarks, special methods he hoped would be adopted, but unfortunately, all people were more or less selfish, and he supposed for the time being they would continue to be, and until human nature was changed he did not think there was much hope of securing the very much desired whole-hearted co-operation, unless some compensating advantage could be obtained.

Mr. Ashley Carter said he desired to say in regard to the question of the standardisation of tools that about nine months ago a very powerful Commission was formed in America to go into the question of the standardisation of tool joints. That Commission had already made fairly wide researches into the question, and was steadily working with the object of carrying out the purpose in view, but the Commission was of opinion that it would take eight years before standardisation could be thoroughly completed.

An Economic Study of Petroleum Mining by Underground Drainage.

A Communication presented by PAUL DE CHAMBRIER, at the International Congress of Liquid Combustibles, organised by the Society of Chemical Industry, Paris, October, 1922.

Translated and abridged from the French original, by J. A. LAUTIER.

(Read by the SECRETARY, COMMANDER R. E. STOKES-REES, in the absence of the author.)

INTRODUCTION.

THE general idea formed as to the exploitation of petroleum by shafts and galleries is not always very exact. And the object of this paper is to not only reply to objections and criticisms, some of which may be well-founded, but also to show the economic importance of an effort to diminish, as far as may be possible, the wastage which at present exists in the ordinary methods of working oil mines.

Basing our arguments upon the results obtained by the Pechelbronn Mines, both by present and former workings, and having regard to the natural laws upon which the success of drainage by galleries depends, we shall be able to see what output may be expected, and the conditions under which it will compare with the exploitation by borings.

SHORT HISTORY OF PECHELBRONN UNDERGROUND DRAINAGE.

A.—FORMER WORKINGS.

The early workings underground at Pechelbronn, which date back to 1735, took the form of digging into the sides of the hills; but in 1745 the Alsatian miners took up the method of drilling wells, and up to 1867 the depths had been gradually increased to 72 metres. The usual plan was to work the well out and then fill it up again with the sand. The sand extracted was washed by boiling water and gave off a very thick grease of a density from 0·965 to 0·975, which was termed "graisse d'asphalte."

The method of collecting the oil from the oozings or leakage from the sands was first taken up in Alsace in 1866, from what is known as the "George" well, which is situated in a part of the Pechelbronn territory, where a richer oil had been found than in former wells.

Unexpected and important results attended this plan. It saved the Pechelbronn Oil Industry, which had become somewhat precarious, owing to the fall in prices for mineral oils. The oil came oozing out into the galleries of its own accord, and greatly simplified the working. The working out, washing of sands, and refilling of the shafts, were dispensed with, in addition to a considerable amount of collecting and transport, and the cost of obtaining the crude oil—which they termed "graisse vierge"—was greatly diminished. In addition, the exploiting company, Le Bel and Co., installed a refinery, which permitted distillations of higher value to be extracted.

It is to be noted also that from a general point of view the events of 1866 marked the first effort to obtain petroleum by the method of underground drainage.

The lenticular deposits of sand thus exploited had a width of 16 to 19 metres, with a thickness of 2·30 metres to 3·20 metres, and extended for a distance of 300 metres by two parallel galleries about 16 metres apart, and with a slightly falling gradient as they advanced.

These workings, rich in heavy oil, contained very little gas, which was a fortunate coincidence for a mine worked without ventilation or any air-shaft. But with the small size of the working the production in oil was only from 0·5 to 0·6 per ton. Owing to insufficient air, however, and through serious accidents recurring, the "George" well was abandoned after nine years' working.

From 1875 to 1888 a somewhat curious plan of working was followed in two new shafts, the "Henry and André," which went to a depth of 70 to 100 metres, where a large bed of the impregnated sands had been struck. Inclined galleries were cut out, into which the thick oil oozed under pressure from the gas naturally in the bed. Mr. Langrogne called this the "indirect method," but it was not without its difficulties, for at times there were incursions of oil, water, and sand, which filled the galleries for several days at a time. This peculiarity had never been witnessed in any of the older workings, neither has it been observed in later years. It has been attributed to four causes simultaneously—the supersaturation of the sand, the viscosity of the oil, the presence of water, and the pressure of gas.

Probably, the Le Bel Company, later on, would have drained the "Henry-André" workings, but for new circumstances arising. In 1882 a boring of 139 mètres depth struck upon a free light oil of 0·875 density, quite a different quality to the asphalte-grease and the virgin-grease previously found. A series of successful borings were made during the following years, but in 1888 the method of working by galleries, which had now been followed for 154 years, was abandoned.

B.—Renewal of Underground Working in 1916.

We need not enter here into the reasons which decided the Pechelbronn Mines to renew the system of underground working, but in view of the fact that the petroleum beds were charged with gas, the decision was a bold one. Although it was expected that the oil beds would be found with the liquid oozing or leaking, the plant installed was for taking out the sand and separating by washing in hot water, a building being expressly built close to the boring.

The company were agreeably surprised to find abundance of oil oozing from the sands which had already been considered "worked out" by previous borings, but were still unable to understand the flowing oil, except as a temporary incident. The main object of the new shaft was to liberate the gases and thus permit working to be undertaken in the ordinary way, and the company quite expected the "oozing" to cease in a matter of five or six years' time, and the future principal source of revenue would have to come by the use of classic methods.

It is interesting to refer to the erroneous figures on which the exploitation at that time was based. The expected production per ton of sand was as follows:—

By leaking or oozing	11 kilos =	24·20 lbs.
From washing	67 „ =	147·40 „
Oil still retained in the sand, or lost ..	22 „ =	48·40 „
	100 „ =	220 „

The irregularity of impregnation and the variable disposition of the beds not permitting of exact figures being established for the production by the drainage system of Pechelbronn, we have had to take the following approximate figures.

One ton of sand from a boring already exploited can give 52 kilos of oil by oozing, and 48 kilos will remain adhering to the sand.

On the other hand, from a "virgin" deposit there may be obtained:—

By boring	20 kilos	(44 lbs.)	say 16·7%
By drainage	52 „	(114½ lbs.)	„ 43·3%
By sand washing	38 „	(83½ lbs.)	„ 31·7%
Losses	10 „	(22 lbs.)	„ 8·3%
			100·0%

We will now examine the various causes which tend to vary this approximate production.

C—Action of Drainage.

The rational exploitation of crude petroleum is based upon the study of the impregnation of porous rocks. Many books have

been published on this subject, and without pretending to add anything new to the information given in them as to the geological or physical changes, the porosity of the sands, adhesion, absorption, the *rôle* of the viscosity of the oil or gas or water, we shall simply try to deduce from natural laws the facts which apply more especially to underground drainage of petroleum-laden sands.

The Physical Factors.

By adhesion every grain of sand is encased by a thin film of oil. This oil is naturally lost in the drainage and the space it occupied is taken up with other particles of oily sands, water, gas, and earthy matters.

In certain physical and chemical conditions the colloidal and asphaltic bodies contained in the crude oil become attached or absorbed in argillaceous matter, and the proportion of such impurities in the sand will have its effect on the quantity of crude oil to be extracted, and on its quality; and the earthy products cannot easily be separated by washing, or by absorbents.

The percentage of this earthy matter is very variable in the Pechelbronn grounds. It runs from 5 to 40 per cent., which explains the variations of saturation observed in the strata. An average of 15 per cent. may be counted upon. And these impurities also impede the circulation of the liquids.

It is, of course, well understood that the quantity of oil absorbed by a deposit depends upon the porosity of the sand, which will vary according to the fineness of the grains, their form and arrangement, as well as upon the foreign bodies embedded. Part of the oil is therefore susceptible of exuding, but a quantity is retained by capillary attraction. In strata which are composed of large grains or regular form the oil leaves the free spaces, but in the fine grain strata, more closely packed, the drainage is impeded, and the results are less satisfactory.

It may be mentioned in passing, however, that drainage cannot give constantly the same results, because the height to which a liquid will ascend depends upon the superficial tension. On the other hand, the height of ascension of an effervescence in a capillary tube is in inverse ratio to its density, that is to say, as the quantity of gas in it is greater. And the Pechelbronn figures as to the production of the borings being quite approximative, they cannot be applied to other rocks or deposits without a preliminary study of the particular locality.

The viscosity of the oil has an important influence on the amount recovered by drainage. A fluid oil will, of course, offer considerable resistance in its passage between the interstices of the stratum.

But with the thick oil the grains slide more easily, and to such an extent that they may invade the workings like a quicksand, a circumstance which formerly happened at Pechelbronn.

Actions of Gas.

It is also important to study the part played by gas in the migration of the crude product, and the saturation and drainage. Oil and water mixed will, if left at rest, gradually separate in two distinct layers. The separative action, however, is so weak that it takes considerable time if the liquids are contained in a capillary medium. In this instance gas will act as the displacing power. It is formed by the slow decomposition of the oil, or the matters from which it is derived, and assembles in the upper part of the stratum and expands there.

The effect may be compared to distillation which requires the existence of a free space for the reception of the more volatile products. And if petrol gas forms in the stratum which is saturated with oil it will remain there, and the pressure will continue to increase. There will be no movement unless there is a contraction of the earth's crust, which may cause an opening to be made, and the fluids will find an outlet, and penetrating into adjoining strata separate from each other.

Boreholes of only an inch or two in diameter on reaching an oil stratum, will cause but a very limited action. There is, at first, a partial depression of gas, which escapes little by little as the boring continues, and when the oil recovered by pumping is too small to cover the costs the work is abandoned.

As fast as an exploited ground is used up free space is formed in the upper portions, where some of the gas gradually accumulates. This continual ascension of gas, which until then has been dissolved in the oil, holds the petroleum in suspense in the porous rock, an effect which is increased by the fall in temperature. This fall in temperature increasing the viscosity of the oil forms a new obstacle to the free flow of the liquid.

The other portion of the gas remains, however, in solution or suspension in the crude petroleum, for the deposit is still under pressure—a factor not to be neglected.

When a drilling is abandoned the oil between the grains of sand can no longer escape, for the bubbles of gas enclosed no longer possess the necessary force to circulate in the minute canals of the porous rock which they obstruct.

By opening up the strata therefore by galleries or tunnels the state of equilibrium is destroyed, and all gas dissolved in the oil bubbles out freely in consequence of the depression which has taken place, each bubble acting as a "piston," and driving the oil out of

the deposit. As there is no renewal of the gas the effervescence disappears, and a free passage is left for the crude oil to flow away to the drainage.

Leakage or oozing is produced by the rush of gas and the separation of the fluids.

Action of the "Essence" Vapours.

After the action of drainage the quantity of crude oil remaining in the sands might be expected to remain constant for sands of the same nature. This, however, has been found not to be the case. In some of the old galleries, formerly productive, and where gas was particularly active, the quantity remaining has been found to be as low as 1 per cent. only. And in the oil from the same mine some differences of density have been observed. The experiments which will enable us to define the condition under which the sand under those circumstances can be freed from the oil have not yet been concluded. It has, however, been noted that at points where the gas currents are particularly abundant, and at the time when this gas emerges into the tunnels, a fall in temperature is produced which is sufficient to permit the petroleum vapours, with which it is charged, to partially condense in the sand. This essence, when dissolving in the oil, flows away more easily, because of its lowered viscosity.

If this hypothesis be correct it may be argued that the yield by drainage from deposits rich in essences might very well be superior to that of Pechelbronn.

Quality of the Oil.

The yield by distillation of the Alsace crude light oils of 0·875 to 0·895 density, is about the following :—

Essence (petroleum spirit)	4%
Petroleum	23%
Intermediate oil	10%
Various lubricating oils	35%
Paraffin	2%
Residue, pitch, and loss	26%
	100%

It is, therefore, an oil very asphaltic and poor in petroleum spirit. Would the exploitation by galleries of a crude of lighter quality be practicable ? Oil certainly circulates more easily in porous beds ; the drainage would be more effective ; distance between the tunnels could be increased, and the cost of extraction consequently reduced.

The idea generally formed with regard to working by shafts and tunnels is that it is not applicable to deposits of crude light oil,

owing to the resulting loss of essence and the danger from the gas. The loss through the light gasolines being carried away with the gas is unavoidable. Their recovery when diluted with the air is an impossibility.

On the other hand, this loss of gas and gasoline is a very slight matter as compared with the loss through the abandoning of a deposit, which, after being exploited by drilling, may still contain 80 per cent. of the oil with which it was originally impregnated.

There remains to be examined the most important criticism—that of the danger of such an exploitation. But this is mainly a matter of ventilation and the planning of the underground workings. The coal mines known to be "fiery" are not abandoned because of that characteristic; they are worked in a special manner.

And the ventilation of simple tunnels or drives is an easy matter. Should it happen that working at the "face" becomes impossible it will be sufficient to wait until the liberation of gas is diminished, and then drain the rock provisionally by horizontal bore-holes. Finally, it is always permissible to so control the progress of work that the velocity of the oil leakage is diminished so that it allows of access to the face of the working. If necessary, the "indirect" method, as previously mentioned, practised at Pechelbronn from 1875 to 1888, could still be employed.

Summary.

To fully understand the action of underground drainage it is necessary to consider the forces which are at work to set the oil in motion, and the opposing forces which balance them. The object of the drainage is to upset this equilibrium.

The active forces are: the gas pressure, its force of ascension, and the specific gravity of the oil.

The opposing reactions are caused by the resistance of the sand to the flow of liquids and gas, by the viscosity of the oil, and by capillary action. The motive power of the gas may also be decreased by its solubility in oil.

Under sufficient pressure the gas succeeds in overcoming these resistances and escapes; not only infiltrating between the sand grains covered with oil, but also into the oil itself, which it displaces on its journey without being able to drive it out entirely from the capillary region where it is found.

By its force of ascension the gas rises above the level of the crude petroleum, seeking in the upper part of the deposit the path of least resistance, where there is the least oil to be displaced. When the pressure diminishes the state of equilibrium is reached and is maintained so long as the gas does not communicate freely with

the air. The deposit becomes inert or unproductive, as in the case of exploitation by drilling.

The specific gravity of the oil is, in our opinion, a very feeble force, and would not overcome the resistance offered to the flow by a thickness of sand unless the oil were put in motion by the gas.

Drainage allows the gas to regain its activity and make use of its tension to the greatest extent, owing to the fact that gas solubility in oil diminishes with the pressure, and consequently its gradual issue causes an uninterrupted ebullition in the deposit, which is indispensable to starting the motion of the oil. Drainage has, therefore, the effect of diminishing the resistance offered by the porous rock to the flow of the fluids.

Yield by Drainage.

The first attempts at Pechelbronn of exploitation by shafts or tunnels in the deposits of crude light oil were based upon laboratory experiments—experiments in saturation, and drainage of sand—which gave the first ideas as to the quantities of crude oil still remaining in an oil-bearing basin exhausted by drainage. It was very difficult to imitate the same conditions of a sand deposit completely heaped up, where the natural gas is dissolved under great pressure in the oil. It followed that these experiments, whose results were entirely due to the action of gravity, showed evidence of a feeble production of oil from leakage, but promised an important yield by scrubbing the sand. The results from the actual mining operations were, on the contrary, quite to the advantage of the "leakage" method, whose yield was double or treble the quantities which had been formerly extracted from the same deposit by pumping. This seems to us to prove again that gravitation does not play the principal part in underground drainage.

On taking the total quantity of "mètres" of galleries worked out, with the production of the deposit being worked, one obtains the real production by drainage. It may vary from one year to another, according to the nature of the ground being worked, the richness and impregnation of the rocks traversed, and the plant necessitated by the workings.

The Theoretical Yield.

The theoretical yield from one "mètre" of drainage, where the country is homogeneous and regular, is easy to calculate. The deposits should be divided by tunnels into a series of rectangles. For each new section it will only require a tunnel forward and

another across, so that the lengths are equal to the dimensions of a rectangle. Suppose that :—

R = the yield in tons per "mètre" of tunnel to be calculated.

s = coefficient of leakage—that is, the yield of one cubic "mètre" of sand.

H = the richness of the bed.

$\left.\begin{matrix} a \\ b \end{matrix}\right\}$ = length and breadth of the rectangle.

The yield per "mètre" of tunnel will be found by dividing the content of the "leakage" oil of one pillar by the sum of two of its sides. Then we shall have the equation :—

$$R = \frac{H\,a\,b\,s}{a + b}$$

If the deposit be divided into squares the relation will become :—

$$R = \frac{H\,a\,s}{2}$$

In a general way, if the total quantities of oil from leakage to be obtained from a deposit depend upon its volume and its degree of impregnation, the yield per "mètre" of tunnel will be proportional to the richness of the bed.

The Cost Price.

If the underground exploitation is limited to the drainage of the deposit it does not constitute a true mining proposition, as it only consists of cutting drives whose expense is not great. It is easy to calculate the cost of these.

The cost price of oil extracted by drainage, "P," will be obtained by dividing the cost of a tunnel one "mètre" in length, "p," by its yield in oil, "R."

$$P = \frac{p}{R}$$

Now, since—

$R = \frac{H\,a\,b\,s}{a + b}$ the equation becomes—

$$P = \frac{p\,(a + b)}{H\,a\,b\,s}$$

This equation permits the drawing up of a programme of exploitation and to calculate the cost price of the crude oil of a deposit, of which the dimensions and degree of impregnation are known.

The relation between the oil production and the number of "mètres" of tunnel will remain almost constant, in a deposit regularly distributed and homogeneously impregnated. If, in addition to that, the oil-bearing sand is strongly impregnated; the beds of large dimensions; the ground has sufficient variation in levels; and the oil to be extracted is of light viscosity; then the yield by drainage, or in other words the cost price of the crude petroleum, will be such that it will be easily able to compete with the cost price of oil obtained by surface borings.

And these conditions are found united in petroleum basins of countries of high production, where the yield per "mètre" of tunnel would easily be double or even treble that of Pechelbronn, where all these conditions are wanting. At the place where the yield by boring has been great the yield by drainage will be the same.

Without the conditions of stratification and impregnation of the deposit underground drainage will, of course, be inapplicable; also in countries where the market value of the crude oil is very low, or in other words, in places where there are still eruptive springs, or wells of very great yields.

The principal object to be attained by underground exploiting is not merely the obtaining of a very cheap petroleum, but the real utilisation of wealth unexploitable by the ordinary methods. The system will apply quite well to the extraction of oil of superior quality.

The conditions to which the underground drainage will be applicable for the extraction of crude petroleum at the same price as by boring may be determined in certain cases. We have condensed in two tables some examples which will show the manner in which it will be possible to work out the comparative estimate of the cost price of crude oil.

FIRST TABLE.—Example of calculation of the cost price of crude oil.

A.—*Borings.*

DATA PRESUMED.—In a petroleum basin partly exhausted the levels still exploitable are deep and the proportion of springs is not great. One would therefore calculate on an average of 1000 "mètres" for boring to do, in order to discover either an important spring or several springs. Expressed in terms of these 1000 "mètres" of boring the total production of these springs up to their complete exhaustion varies from 1000 to 3000 tons. The

other conditions supposed in the following examples take account of sensible differences which may exist in this industry :—

Total production (tons)	1000	2000	3000
Cost price per "mètre" drilled (francs)	250	200	150
Cost of extraction per ton (francs)	60	30	15

TOTAL EXPENDITURE IN PROSPECTION AND EXTRACTION.

		Francs.	
Drilling	250,000	200,000	150,000
Extraction	60,000	60,000	45,000
Total	310,000	260,000	195,000

DEPRECIATION OF PLANT AND INSTALLATION.

		Francs.	
Drilling	40,000	35,000	30,000
Extraction	60,000	50,000	40,000
Total	100,000	85,000	70,000

COST PRICE PER TON OF PETROLEUM.

		Francs.	
Prospection and extraction	310	130·00	65·00
Depreciation	100	42·50	23·33
	410	172·50	88·33

SECOND TABLE.—Example of calculating the cost price of crude oil.

B.—*Drainage.*

DATA PRESUMED.—A deposit of average depth, without irregularity of strata; abandoned after having yielded by drilling and pumping 60,000, 80,000 or 120,000 tons of oil. If drained it would yield 2½ times more—viz.: 150,000, 200,000 or 300,000 tons. These quantities could probably be extracted in one single claim, consisting of two shafts with their accessories. The entire plant to be redeemed after exhaustion of the deposit. The other data are given within very wide limits in order to show that a judicious choice of the deposit to be drained would lead to very favourable results for the method of extraction by underground drainage. The coefficient for leakage or "oozing" is supposed to be one-tenth of a ton of oil per cubic metre of sand :—

Total production (tons)	150,000	200,000	300,000
Richness of the beds ("mètres")	3	4	5
Sectioning ("mètres")	50×50	50×100	100×100
Cost price per mètre of tunnel, including all mining expenses (francs)	2000	1500	1000
Primary establishment charges (francs)	6,000,000	5,000,000	4,000,000

COST PRICE PER TON OF PETROLEUM.

		Francs.	
Extraction	266·67	112·50	40·00
Depreciation	40·00	25·00	13·00
Total	306·67	137·50	53·00

Conclusions.

From the arguments and figures we have given we make the following conclusions :—

1.—The drainage of a deposit, impregnated with a very viscous oil and containing but little gas, will have a bad yield. Such an exploitation runs the risk of being, if not impossible, at least a very expensive undertaking, owing to the influx of moving sand which may take place. This is proved by the first attempts at underground drainage as carried out on the Pechelbronn property in the years 1867 to 1888.

2.—The very advantageous results obtained in Alsace by draining deposits impregnated with a relatively light crude oil are of the greatest interest to the petroleum industry, especially in view of the conditions of this exploitation being by no means favourable from the point of view of output per "mètre" of tunnel.

3.—The yield by drainage from a deposit of great extent and of regular character, impregnated with oil more fluid than that of Pechelbronn, would probably be very remunerative. The evacuation of the excess of gas is a technical question remaining to be studied.

4.—The contents in oil and in gas of a deposit already exploited by drilling is difficult to calculate in advance. We believe, however, that for sands of equal porosity the coefficient for leakage will only vary within very narrow limits.

5.—The cost price of the oil to be extracted by drainage of a regular deposit, whose degree of richness is known, may be calculated fairly closely. The dimensions to be given for the sectioning will depend on the viscosity of the oil, on the gas pressure, and probably also on the dip of the strata.

6.—Extraction by drainage permits at least the trebling of the quantities of oil obtainable from the deposit, thus increasing the value of a concession in the same proportion.

7.—This method of exploitation is applicable to all localities where the underground work does not offer too many difficulties; in petroleum basins where the costs of extraction by drilling becomes constantly higher, owing to the exhaustion of the deposits; and generally speaking, in all countries where the market value of petroleum has not been depreciated by an excess of production. It would be specially suitable for the extraction of high-grade oils.

8.—We consider that this rational method of exploitation of crude oil has certainly a great future before it if the example given by the Pechelbronn Mines is understood and applied to other deposits.

PERCENTAGE YIELD OF 100 KILOS (OR OF 100 LITRES) OF OIL-BEARING SAND.

	Density of sand.	% by weight.	% by volume.
Maximum. Exceptional case—			
Primitive impregnation	1·84	13·00	27·20
After exhaustion	1·65	1·00	1·90
Yield by drainage	—	12·00	25·30
Minimum. Exceptional case—			
Primitive impregnation	1·76	8·00	16·00
After exhaustion	1·71	4·80	9·30
Yield by drainage	—	3·20	6·70
Average admitted—			
Primitive impregnation	1·79	10·00	20·40
After exhaustion	1·71	4·80	9·30
Yield by drainage	—	5·20	11·10

The sand carefully screened and extracted from the tunnels often contains a little more than 4·80 per cent. of oil; but from the refuse-dump, where it is placed, there drips again a certain quantity of oil, which is collected.

STATISTICS CONCERNING UNDERGROUND WORKING AT PECHELBRONN.

Periods	1812-1866	1867-1888	1917-1921
Years	55	22	5
Tunnels (in mètres)	30,000*	3430	8472
Products obtained	Asphalt-grease	Virgin-grease	Crude oil
Production in tons	4959	14,427	68,563
Method of extraction	Working out	Drive and notching	Drive
Tons per mètre of tunnel	—	4,20	7,80
Saturation of sand (%)	Very small	Average	Considerable

* Uncertain.

AVERAGE PROPERTIES OF CRUDE PRODUCT.

Density	0·970	0·945	0·880
Viscosity (Engler) at 50°	45	18	1·20
Flash point	165	135	15*

* Uncertain.

COST PRICE OF TON OF GREASE OR OIL EXTRACTED.

Years.	Product.	Francs.
1840-1842	Asphalt-grease	300
1867-1881	Virgin-grease	76
1882-1889	Crude oil from borings	14
1890-1906	" " " "	16
1906-1914	" " " "	40

The Chairman (Mr. E. H. Cunningham Craig) said a great deal could be learned from the paper from the point of view of oil production. He had recently been in two oil mines, in which entirely different conditions from those at Pechelbronn existed, and there, he was sorry to say, up to the present no great success had been achieved, chiefly because the galleries had met with difficulties, and had not yet entered really rich zones; but he was perfectly convinced there were great possibilities in front of that method of extracting oil.